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MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

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THE MANGANESE-ORE DEPOSITS OF INDIA, *by* L. LEIGH FERMOR, A.R.S.M., B.Sc. (London), F.G.S., *Assistant Superintendent, Geological Survey of India.*

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THE

MANGANESE-ORE DEPOSITS OF INDIA

CONTENTS

SUMMARY OF CONTENTS.

	Pages.
Detailed Contents	ix—xlvii
List of Plates	xlix—liii
List of figures in the text	lv—lvii
List of tables	lix—lx
Synopsis of Parts I, II, and III	lxiii—xcviii
Part I.—Introduction and Mineralogy	1—232
Part II.—Geology (Mode of Occurrence and Origin) . .	233—408
Part III.—Economics and Mining	409—610
Part IV.—Description of Deposits	611—1158
Appendix I.—Bibliography of Indian Manganese.	
Appendix II.—Geographical Index.	
Index.	

DETAILED CONTENTS.

PAGE.

SYNOPSIS OF PARTS I, II, AND III . . . . . lxv—xcvii

PART I.

INTRODUCTION AND MINERALOGY.

CHAPTER I.—**Introduction.**

History of the investigation 3
Scope of this Memoir 5
Acknowledgments 6
Analytical work 8
The visitor to India 9
Literature of Indian manganese-ore deposits . . 9
Literature of foreign manganese-ore deposits . . 12
Nature of manganese 16
Origin of the word manganese. 17
Recognition as a new element. 17
Distribution in Nature 18
In the mineral kingdom 18
In the vegetable kingdom. 19
In the animal kingdom 20

CHAPTER II.—**Mineralogy: General.**

Wide distribution of manganese in minerals and rocks 21
Colours of manganese minerals 21
Occurrence of manganese minerals 22
List of known manganese minerals with their chief properties 23
List of Indian manganese minerals 34
List of associated non-manganiferous minerals . . 35
New species and varieties 36

CHAPTER III.—**Oxides.**

Pyrophanite. 37
Dysluite 37

PAGE.

CHAPTER III.—*continued.*

Manganmagnetite 38
Occurrence 39
Origin 40
Hausmannite 41
Vredenburgite 42
Characters and occurrence 42
Chemical composition 43
Sitaparite 49
Characters 49
Chemical composition 50
Braunite 52
Occurrence 53
Crystallographic characters 55
Value of the fundamental angle *pp'*. . . 55
Length of the vertical axis, *o* . . . 56
The Kájlidongri crystals 57
The Kácharwáhi crystals 57
Twins 58
A new form 59
The Lohdongri crystals 60
The Kodegáon crystal 60
Three new forms 61
Striations 61
Size of crystals 61
List of forms on Indian and foreign braunites 61
Physical characters. 63
Magnetic characters 63
Chemical composition 63
Appendix—Analysis of Sitapár braunite . . 76
Polianite 77
Pyrolusite 78
Characters 78
Occurrence 79
Analyses 81
Manganite 83
Characters 83
Occurrence 83
Chemical composition 84
Pseudo-manganite 84

PAGE.

CHAPTER III.—*concluded.*

Specimens from Mysore and Goa . . . 85
Comparison of properties of manganite, pseudo-manganite, and pyrolusite 86

CHAPTER IV.—**Manganates and Carbonates.**

Hollandite 87
Occurrence 87
Physical characters. 89
Crystallographic characters 89
Fibrous hollandite 90
Hollandite in the Chhindwára district . . 90
Hollandite in the ores found in the crystalline limestones, Nágpur district 90
Massive hollandite, Bálághát district . . . 90
Chemical composition 91
Coronadite 96
Specific gravity 97
Psilomelane 97
Occurrence 97
Physical characters. 98
Form 98
Specific gravity 99
Chemical composition 99
Descriptions of specimens 106
Guguldoho 106
Avagudem 106
Tekrasai 107
Calculation of analyses of braunite-psilomelane ores 108
Calculated analyses of psilomelane . . . 110
Beldongrite 115
Wad 116
Characters 116
Occurrence 117
Chemical composition 118
Garbhám specimen 121
Kodur specimen 121
Ankerite 121
Rhodochrosite 122
Characters 122
Occurrence 123

PAGE.

CHAPTER V.—Silicates—Pyroxenes and Amphiboles.

Manganese-bearing pyroxenes 125
Blanfordite 125
The Kácharwáhi occurrence 125
Original account 125
Crystallographic characters 126
The Rámdongri occurrence 127
The Kájlidongri occurrence 127
The Nárukot occurrence 128
Manganhedenbergite 130
Occurrence and characters 131
Chemical composition 131
Brown and yellow pyroxenes 132
Occurrence 132
Composition 133
Schefferite and urbanite 133
Pyroxenes of the Vizagapatam district . . . 137
Brown pyroxene 137
Green pyroxene 137
Brownish green pyroxene 137
Colourless pyroxenes 138
Jeffersonite 138
Rhodonite 139
Characters 139
Microscopic aspect 139
Identification 140
Occurrence 140
Alteration 143
Use as an ornamental stone 144
Manganese-amphiboles 145
Foreign manganiferous amphiboles . . . 145
Dannemorite 146
Richterite 146
Yellow and greenish-grey amphiboles (Dannemorite) 147
Central Provinces 147
Kájlidongri 149
Winchite 149
Occurrence 149
Crystallographic characters 150
Pleochroism 152

PAGE.

CHAPTER V.—*concluded.*

Extinction angles 153
Double refraction 154
Separation of the mineral 155
Specific gravity 156
Chemical composition 156
Juddite 159

CHAPTER VI.—**Silicates** (*continued*)—**Garnets.**

Manganese-garnets 161
Characters of garnets 161
Composition of garnets 161
Isomorphous replacement 162
Origin of the term 'spandite' 163
Use of the term 'spessartite' 164
Origin of the term 'grandite' 165
Analyses of Indian manganese-garnets . . 166
Spessartite 168
Occurrence 168
Abundance and economic importance . . 169
Localities for good crystals 170
Crystallographic characters 172
Cleavage 174
Structure zoning 175
Striations 175
Specific gravity 175
Colour 175
Colour zoning 177
Inclusions 177
Anomalous double refraction 178
Microscopic aspect 178
Spandite 179
Chemical composition 179
Occurrence 179
Characters 180
Grandite 181
Aplome 182
Calderite 182
Occurrence 182
Chemical composition 183

CHAPTER VII.—**Silicates** (*concluded*)—**Epidotes, Micas, etc.**

Piedmontite 187
Characters 187

PAGE.

CHAPTER VII.—*concluded.*

Mangan-epidote 187
Thulite and withamite 188
Distinction between the different manganiferous epidotes 188
Occurrence in India 188
Characters of Indian piedmontites . . . 190
Ilvaite 192
Carpholite 192
Manganese-micas 193
Caswellite 194
Alurgite 194
Manganchlorite 194
Indian manganese-micas and chlorites . . . 195
Manganchlorite 195
Brown micas (Manganophyllite ?) 196
Alurgite 197
Ottrelite 199

CHAPTER VIII.—**Titano-silicates, Niobates, Phosphates, and Tungstates.**

Greenovite 201
Tscheffkinite 202
Columbite 203
Manganapatite 205
Triplite 206
A manganesian phosphate 207
Wolfram 208
Characters 208
Occurrence in India 208

CHAPTER IX.—**Associated Non-manganiferous Minerals.**

Graphite 211
Chalcopyrite 211
Pyrite 212
Pyrrhotite 212
Halite 212
Rose quartz 212
Amethyst 213
Chalcedony and chert 213
Opal 214
Iron-ores 214
Hematite 215
Limonite 215

CHAPTER IX.—*concluded.* PAGE.

Magnetite 215
Martite 216
Gibbsite 216
Microcline 217
Sapphirine 217
Lithomarge and kaolin 217
Arsenates 218
The Sitapár arsenate 218
The Kájlidongri arsenates 219
Distinction of arsenates, apatite, and barytes . . 220
Barytes 220

CHAPTER X.—The Identification of Manganese Minerals.

Micaceous structure 223
Colour 223
Tests for manganese 224
The black or grey minerals 225
Key to the identification of the black and dark-grey iron, manganese, and chromium minerals. . . 226
Key to the identification of the black, dark-grey, and bronze-coloured manganese-ores . . . 228
White minerals 231

PART II.

GEOLOGY (MODE OF OCCURRENCE AND ORIGIN).

CHAPTER XI.—General.

General 235
The Archæan complex 235
The oldest gneisses 236
The schistose gneisses and the Dhárwárs . . . 236
The plutonic intrusives (Bundelkhand granite, charnockite series, etc.) 237
The great eparchæan unconformity 237
The Puraná formations 238
Classification of the pre-Cambrian 238
Derivation of the rocks ranging in age from Cambrian to recent 238
The ultimate source of the manganese-ores . . 239
Manganese-ore deposits found in rocks of any age . 239
Distribution of the manganese-ores and minerals of India according to formations . . . 239
The Khondalite Series 241
Vizagapatam, Ganjám, and Orissa 241

PAGE.

CHAPTER XII.—**The Kodurite Series of Vizagapatam and Ganjam.**

Vizagapatam district 243
The calcareous or calc-gneisses 243
The kodurite series. 244
Relations of the kodurite series to the other crystallines 244
The kodurite series of igneous origin . . . 247
Nomenclature of the kodurite series . . . 249
Pegmatite and vein quartz 250
Minerals of the kodurite series 250
Quartz 251
Felspar 251
Apatite 251
Spandite 251
Manganese-pyroxenes 252
Biotite 252
Graphite 252
Sphene. 252
Manganmagnetite 253
Petrology of the kodurite series . . . 253
Magmatic differentiation of the series . . 254
Localities for rocks of the series . . . 254
Ganjám district 255
Chemical composition of kodurite 256

CHAPTER XIII.—**The Kodurite Series**—*concluded.*

The Alteration of the Kodurite Series and the Formation of Manganese-ores 262
The replacement of quartz 263
The alteration of the felspar 263
The formation of chert and opal . . . 263
Potash removed in solution as carbonate . . 264
Alteration and replacement of apatite . . 264
Replacement of spandite. 265
Alteration of spandite 265
Formation of manganese-ores by replacement of the kodurite rocks 266
Replacement of the non-manganiferous varieties. 266
Minerals replaced by manganese-ore . . . 267
The removal of alumina 268
Replacement of the manganiferous varieties . 268

CHAPTER XIII.—*concluded.* PAGE.

Formation of manganese-ores by alteration *in situ* of manganese-silicate-rocks . . . 269
Alteration took place under oxidizing conditions . 270
The removal of the alumina 271
The ores formed in three ways 272
Ferric oxide in the ores 272
Baryta in the ores 273
Comparison with the Brazilian deposits . . . 273
The Depths to which the Manganese-ores extend . 274
Kaolinization 274
Oxidation 276
The zone of fracture and belt of weathering . 276
Ground-water level. 277
Time of formation of ores 278
Depths to which the ores extend . . . 278
Sources of the carbon dioxide 279

CHAPTER XIV.—**The Manganiferous Rocks of the Dhárwár Facies, including the Gondite Series.**

General 280
The Dhárwár period of sedimentation . . 280
The metamorphism of the sediments . . 280
The Transitions 281
The Chámpáner series 281
The Dhárwár series 281
The Chilpi Ghát series 282
The metamorphic and crystalline complex of the Nágpur-Bálághát area 282
The Arávalli series 282
The equivalence of the various series . . 283
'Chámpáner' the prior term 283
'Dhárwár' the most familiar term . . . 283
The term 'Dhárwár' adopted 284
The Deposition of the Manganiferous Sediments of the Dhárwár Period 284
The source of the manganese 285
The Partial Metamorphism of the Manganiferous Sediments 286
Formation of primary ores 286
Localities for primary ores 287
Formation of outcrop or recent secondary ores (lateritoid) ores 287
Localities for outcrop secondary ores . . 287

CHAPTER XIV.—*concluded.* PAGE.

The More Complete Metamorphism of the Dhárwárs . 288
Primary manganese-ores formed by the metamorphism of manganese-oxide sediments . . 288
Formation of the manganese silicates, spessartite and rhodonite, in the ore-bodies . . . 289
Liberation of water, oxygen, and rarely of carbon dioxide 291
Formation of manganese silicates at the peripheries of deposits 292
The banded structure of the ore-bodies . . 292
Apatite 293
The Alteration of the Manganiferous Silicates . . . 293
Re-conversion of spessartite and rhodonite into oxidized ores (deep secondary ores) . . 293
Time of alteration of the manganese silicates . 294
Method of alteration of the manganese silicates . 295
Mineral Veins and Intrusives 295
Percolation of mineralized waters during the metamorphism of the ore-bodies 296
Veins traversing the ore-bodies . . . 296
Rocks intrusive in the ore-bodies . . . 296
Manganese-ores in Crystalline Limestones . . . 297
Dhárwárs in the Chhindwára district . . . 298
Origin of the quartz-pyroxene-gneisses and crystalline limestones 298
Origin of the manganiferous limestones . . 300
Piedmontite-gneisses 301
Theory of formation of the manganiferous limestones 301
Formation of piedmontite, spessartite and rhodonite 302
Nodules of manganese-ore and piedmontite . 302
Alteration of manganiferous limestones . . 303
Secondary formation of pyrolusite . . . 303
Manganiferous cherts 303
The mineral composition of the manganese-ores . 303
Folding and faulting of the manganese-ore bands 304
Classification of the Manganese-ores associated with the Dhárwár Series 304

CHAPTER XV.—**The Gondite Series.**

General 306
Origin of the name 306

PAGE.

CHAPTER XV.—*concluded.*

Application of the name 306
Areas in which found 307
The Nágpur-Bálághát area 307
The Origin of the Gondite Series 308
Evidence for igneous origin of the gondite series . 309
Evidence for metamorphic origin of the series . 310
The rocks at Bálághát and Ukua 311
Conglomeratic grit converted into gneiss . . 311
Mica-schists and phyllites of Bhandára and Bálághát 313
The 'country' of the series 314
Main conclusions as to origin 315
The shape of the areas of deposition 315
The number of ore-horizons 316
Deposition took place in lagoon- or lake-like areas 318
Some ore-lenticles due to squeezing and some to deposition in basin-shaped areas . . . 318
Prospecting for manganese-ore at the base of the Chilpis 319
The Gondite Series in Jhábua 319
The Gondite Series in Nárukot 320
Alteration of manganese silicates to manganese-ores took place in Archæan times . . . 321

CHAPTER XVI.—**The Gondite Series**—*continued.*

Mineralogy of the Gondite Series 323
Petrology of the Gondite Series 325
Nomenclature of the gondite series 325
Structure of the bodies of manganese-bearing rocks 326
Dip of the bands of the gondite series . . . 328
Dimensions of the masses and bands of the gondite series 328
Lists of rocks 329
Rocks found in the gondite series as represented in the Central Provinces . . . 329
Rocks found in the series as represented in Jhábua 330
Rocks of the series found in Nárukot . . . 330
Rocks of the series containing braunite . 331

PAGE.

CHAPTER XVI.—*concluded.*

Petrology of the Gondite Series—*concluded.*

Rocks interbanded with the rocks of the gondite series in the Central Provinces . 332
Rocks interbanded with the rocks of the gondite series in Jhábua . . . 332
Rocks interbanded with the gondite series in Nárukot 333
Manganiferous micaceous schists associated with the rocks of the gondite series . . 333
Winchite-bearing rocks 334
Manganiferous rocks forming the 'country' of the gondite series 334
Non-manganiferous rocks forming the 'country' of the gondite series in the Central Provinces 335
Rocks intrusive in the gondite series . . 336
Mineral veins found traversing the rocks of the gondite series 336
Descriptions of more important rocks . . 337
Gondite 337
Apatite-gondite 339
Rhodonite-bearing members of the series 339
Barytes in the gondite series . . 339
Rhodonite-quartz-rock and rhodonite-gondite 340
Amphibole-bearing members of the series 341
Rhodochrosite in the gondite series . 341
Felspar in the gondite series. . . 341
Piedmontite, calcite, and wollastonite, in the gondite series 341
Arsenates in the gondite series . . 342
Pyroxenes in the gondite series . . 342
Blanfordite 343
Black quartzite 343
Red quartzite 344
Manganiferous gneisses . . . 344
Localities for the Rocks of the Gondite Series 345
Areas to prospect for further occurrences of the gondite series . . . 346

PAGE.

CHAPTER XVII.—The Gondite Series—*concluded.*

Chemical Composition of the Gondite Series . . 348
Composition of gondite 348
Composition of rhodonite-quartz-rock . . 352
Alteration of the Gondite Series 353
Evidence pointing to the formation of manganese-ore by the alteration of spessartite and rhodonite 353
The Mansar deposit 353
Association of manganese-ore and spessartite 354
Spessartite changes to manganese-ore . . 354
Alteration of rhodonite 355
Time of alteration of the manganese-silicate-rocks into manganese-ores 355
Hill deposits are dry 355
Highest points of a gondite band consist of manganese-ore 355
Manganese-ore deposits formed before the present topography 356
Probably formed in Archæan times . . 357
The way in which the manganese-silicate-rocks alter to manganese-ores 357
The formation of braunite and psilomelane . 357
The ores are not porous 358
The ores formed by combined replacement and decomposition of spessartite and rhodonite 358
Lack of examples showing solution of manganese 359
Carbon dioxide as the reagent producing alteration 359
Sulphuric acid as the reagent producing alteration 360
Alteration of rhodonite 362
Carbon dioxide the more probable reagent . 362
Rarity of open spaces in the altered rocks . 363
Further reasons for supposing that alteration took place in Archæan times . . . 363
Depths to which the manganese-ores extend . 364
Conclusions as to the Origin of the Gondite Series and the Associated Manganese-ores 364

PAGE.

CHAPTER XVIII.—**Manganese in the Purána, Palæozoic, and Mesozoic Formations.**

Manganese in the Purána Formations . . . 366
Manganese in the Káládgi formation . . . 366
Manganese in the Bijáwar formation . . . 366
Manganese in the Vindhyan formation . . 367
Manganese in the Krol formation . . . 367
Manganese in the Gondwánas 367
Ironstone shales 367
Kámthi group 367
Jabalpur group 367
Manganese in the Lias 368
Manganese in the Lametas 368
Manganese in the Deccan Trap 369

CHAPTER XIX.—**Manganese in Laterite.**

General 370
Origin of the term 370
Division into low- and high-level laterites . . 370
Low-level Laterite. 370
Manganese-ore in low-level laterite . . . 371
High-level Laterite 371
South Indian variety of high-level laterite . . 372
Deccan variety of high-level laterite . . . 372
Theories as to the Origin of High-level Laterite. . 373
The Laterite of the Yeruli Plateau 374
A bauxite-conglomerate 375
The conglomerate formed beneath water, such as in a lake 375
Composition 376
Origin of the Yeruli laterite 379
Necessity of considering each occurrence of laterite separately 380
Lateritic Manganese-ores 380
Result of formation of laterite. 380
The destination of manganese when laterite is formed 380
Lateritoid 381
The Talevádi occurrence 383
Jabalpur and Goa 384
Classification of the deposits of lateritic manganese-ores 385
Economic value of the deposits 385

PAGE.

CHAPTER XIX.—*concluded.*

The Sandur deposits 386
Limitation of the term 'lateritoid' . . . 386
Distribution of manganiferous laterite and of lateritoid 386
Structure and working of the lateritic manganese-ore deposits 387
Mineral composition of the lateritic ores . . 387
Pisolitic (aluminous) manganese-ores . . 388
Chemical composition of the lateritic ores . . 388

CHAPTER XX.—**Manganese in the Tertiary and Recent Formations.**

Lateritic Gravel (Manganese-ore Pisolites) . . 390
Manganese-ore pisolites 390
Detrital pisolites 390
Concretionary pisolites 390
Modes of occurrence 390
Origin of the detrital pisolites 391
Origin of the concretionary pisolites . . . 391
Sections at Mansar and Beldongri . . . 392
Summary of origin 393
Manganese in the Tertiary 394
Manganese in the Siwaliks 394
Manganese in the Fossil-wood Group. . . 394
Manganese in the Post-Tertiary 394
Recent Deposits of Manganese 394
General 394
Deposits in ponds and rivers, etc. . . . 395
Psilomelane deposited at a waterfall on the Pench 395
Manganese oxide deposited in a pond near Rambha 396
Pyrolusite at Pán Kuán 396
Dendrites of manganese oxides . . . 397
Manganese oxides in Pleistocene mammalian remains at Allahabad 397
Manganese-oxide stains in asbestos from Tumkhera Khurd 398
Deep-sea Deposits 398
Summary of origin of deep-sea nodules 403
Deep-sea nodules from the Maldive Islands. 403
Manganiferous Sands and Soils 404

PAGE.

CHAPTER XX.—*concluded.*

Manganese in fault-rock of various ages . . . 404
Manganese-ore in breccias in Central India and the Central Provinces 404
Manganese-ore in fault-rock, Bundi State . . 405

PART III.

ECONOMICS AND MINING.

CHAPTER XXI.—**History of the Indian Manganese Industry.**

General.
The working of manganese-ores by the natives of India. 411
Vernacular names for manganese-ore. . . 412
History of the fluctuations in the price of manganese-ore 413
History of the Modern Manganese Industry in India. 420
Madras 420
Vizagapatam: H. G. Turner and the Vizianagram Mining Co., Ltd. . . . 420
Gordon, Woodroffe & Co., Kovoori Basivireddy, and A. Subha Naidu and Co. . 421
Madras Manganese Co. and the Bobbili Mining Co., Ltd. 421
Sandur State: Messrs. A. Ghose, Jambon & Co., and the General Sandur Mining Co., Ltd. 422
The Central Provinces 422
W. H. Clark, H. Dodd, and the Central Provinces Prospecting Syndicate, Ltd. (Nágpur, Bálághát, and Bhandára) . . 422
H. D. Coggan, Jambon & Co., and the Central India Mining Co., Ltd. (Nágpur and Bhandára) 423
A. M. Gow Smith and the Indian Manganese Co., Ltd. (Nágpur and Chhindwára) . . 424
Jessop & Co. (Nágpur and Bhandára). . 424
Cooverjee Bhoja and the Madhu Lall Doogar Mining Syndicate (Nágpur) . . . 425

PAGE.

CHAPTER XXI.—*concluded.*

Central Provinces—*concluded.*
Bansi Lall Mining Syndicate (Nágpur). . 425
P. C. Dutt, Burn & Co., the Carnegie Steel Co., and Tata Sons & Co. (Bálághát) . 425
Mathura Prasad (Chhindwára) . . . 426
D. Laxminarayan (Nágpur, Bhandára, and Bálághát) 426
Central India. 426
Kiddle, Reeve & Co. (Jhábua) . . . 426
Bengal 427
Hoare, Miller & Co., Jambon & Co., and the Madhu Lall Doogar Mining Syndicate (Singhbhum) 427
Bombay 427
T. B. Kantharia, Jambon & Co., and C. P. Boyce (Belgaum) 427
T. B. Kantharia and the Shivrajpur Syndicate, Ltd. (Panch Mahás) . . . 427
The Bamankua Manganese Co., Ltd. (Panch Mahás) 428
Mysore 428
W. Ainslie, T. J. Newbold, and the Mysore Geological Department 428
W. T. Hamilton Holmes and the Mysore Manganese Co., Ltd. (Shimoga) . . 429
The New Mysore Manganese Co., Ltd. (Shimoga) 429
The Peninsular Minerals Co. of Mysore, Ltd. (Tumkur and Chitaldrug) . . . 430
Miss A. E. Dawson and the Shimoga Manganese Co., Ltd. (Shimoga and Kadur) . . 430
Other concessionaires 430

CHAPTER XXII.—**Statistics of Production of Manganese-ore in India.**

Sources of information 431
Detailed tables of production 433
Deposits that have yielded over 100,000 tons . 447
Comparison of prices with figures of production . 447
Comparison of Indian and foreign manganese-ore production 449
Exports of Indian manganese-ore . . . 455

PAGE.

CHAPTER XXII.—*concluded.*

Distribution of the exported Indian manganese-ore 456
Future Prospects of the Manganese Industry in India. 457
Appendix to Chapter XXII 459
Indian production figures for 1907 . . . 459

CHAPTER XXIII.—**Labour and Costs of Production.**

Labour 467
Labour obtainable 467
Coolie wages 468
Contract and departmental labour . . . 468
Absence of mining castes. 469
Average daily number of workers . . . 470
Benefits of the manganese industry . . . 471
Costs of Mining and Transport 472
Cost of mining 473
Cost of transport to railway 475
Cost of railway transport to port of shipment . 479
Cost of handling at the port of shipment . . 481
Bombay 481
Calcutta 482
Vizagapatam 482
Mormugáo 483
Cost of shipping to Europe and America . . 483
Insurance 484
Destination charges. 484
Total costs of mining manganese-ore in India and delivering it *c.i.f.* at foreign ports . . . 485
Comparison of the costs of production of Brazilian, Russian, and Indian ores . . . 487
Royalty 489

CHAPTER XXIV.—**Valuation and Chemical Composition of Manganese-ores.**

Valuation of Manganese-ores 494
Mining Journal prices 494
Schedule of the Carnegie Steel Co. . . . 495
Requirements made less stringent during 1906 . 495
Use of the Vizagapatam ores 497
Special prices 497
Valuation of ores for chemical purposes . . 497

PAGE.

CHAPTER XXIV.—*concluded.*

Nomenclature of manganese-ores and manganiferous iron-ores 498
Ferruginous manganese-ores 498
Analyses of Indian Manganese-ores 500
Tables of analyses 500
Summary of tables of analyses 509
Analyses of Indian ores expected by buyers . 513
Analyses of the manganese-ores of the world . 515
Analyses of cargoes of Indian and foreign ores landed at Middlesborough 515
Analyses of the manganese-ores of the world . 519
The Rarer Constituents of Indian Manganese-ores . 521
Alumina 522
Baryta 522
Lime 523
Magnesia 523
Potash 523
Soda 524
Arsenic 524
Sulphur 525
Cobalt and nickel 525
Copper 526
Lead 526
Zinc 527
Titanium 527
Combined water 527
Carbon dioxide 528

CHAPTER XXV.—**Value of the Indian Manganese-ore Production.**

Official Indian statistics 529
The *f.o.b.* or export value is the true value to India 530
Tables of export value 531
The *c.i.f.* or true market value 536
Comparison of India's manganese-ore production with that of other minerals 537
The ferro-manganese value of the Indian manganese-ore production 538
Prices of ferro-manganese. 539
Taking the ferro-manganese value, the Indian manganese-ore production is about equal in value to that of coal 541

PAGE.

CHAPTER XXV.—*concluded.*

Enormous loss to India through not manufacturing ferro-manganese 541

CHAPTER XXVI.—**The Mining or Quarrying of Manganese-ores.**

General Principles for deciding whether to Mine or Quarry a Deposit 545
Mode of occurrence and structure of the depcsit . 546
Depths to which manganese-ores extend . . 546
Relation of the outcrop of the deposit to the topography. 548
The value of the ores 548
Nature of the 'country' of the deposit . . 549
The presence of water 550
Cost of timber, tools and plant 550
Cost of labour. 550
Cost of employing technically-trained managers . 551
The Way to Prospect a Manganese-ore Deposit . . 551
The Way to Work a Deposit 553
Four mistakes to be avoided 554
Thick ore-band of moderate dip forming a hill . 555
Thick ore-band of steep dip forming a hill . . 557
Thin ore-band in a hill 558
Thick ore-band cropping out on low ground . 558
Thin ore-band cropping out on low ground . . 559
Scattered ore-bodies in lithomarge . . . 560
Lateritoid cappings 562
Deposits of detrital ore or talus-ore . . . 563

CHAPTER XXVII.—**The Mining or Quarrying of Manganese-ores** *—concluded.*

The Methods Actually Used in Working the Indian Manganese-ore Deposits 567
Indian manganese quarries legally mines . . 568
Classification of deposits. 568
Brief description of methods of working Indian manganese-ore deposits 570
Gravity-inclines and aërial ropeways. . . 570
Mining tramways and railways. . . . 571
Sampling 571
Deposits often badly worked 572
Waste of smalls and dust 572
Waste of low-grade and siliceous lump ores . 573

PAGE.

CHAPTER XXVII.—*concluded.*

Possibility of washing, concentrating, and briquetting smalls and fines 574
Methods of Mining, Washing, Briquetting, etc., used Abroad 574
Briquetting in Brazil 574
Hydraulicking and washing at Crimora in Virginia 575
Methods of mining, washing, etc., employed in Panama 577
Mining of manganese-ore deposits in other parts of the world 578
Grant of Mineral Concessions in India 580

CHAPTER XXVIII.—**The Uses of Manganese.**

Uses in Metallurgy 582
History of the application of manganese in the iron and steel industry 582
Spiegeleisen and ferro-manganese 583
Manufacture of spiegeleisen and ferro-manganese. 584
Manufacture of ferro-manganese in India . . 586
Use of spiegeleisen and ferro-manganese . . 588
Quantity of manganese required in the manufacture of steel 588
Phosphorus and silicon in spiegeleisen and ferro-manganese. 589
Use of the Indian phosphoric ores . . . 590
Use of manganese for de-sulphurizing . . 590
Manganese in foundry practice. 591
Manganese-steel 591
Effects of manganese on iron and steel . . 592
Other manganese alloys 594
Silicon-spiegel 594
Manganese-bronze 594
Metallic manganese 594
The smelting of manganese-ores by the natives of India 595
Kheri 595
Use of manganese as an oxidizer 597
For the decolourization of glass 600
For bleaching powder, bullion melting, and potassium permanganate 601

PAGE.

CHAPTER XXVIII.—*concluded.*

Use of manganese as a colouring material . . 601
For colouring glasses and enamels . . . 601
For pottery 602
Ornamental applications 604

APPENDIX TO PARTS I, II, AND III.

List of atomic weights 605
Table showing composition of certain manganese minerals 606
List showing composition of certain manganese minerals in terms of oxides 606
List of factors for psilomelane and hollandite . . 608
Figures for the conversion of phosphoric oxide into phosphorus 609
Miscellaneous factors 610
Tons and poods 610

PART IV.

DESCRIPTIONS OF DEPOSITS.

CHAPTER XXIX.—Andaman Islands, Baluchistan, and Bengal.

Andaman Islands 613
Baluchistán 613
Bengal 614
Burdwan District 614
Gangpur State 615
Házáribágh District 615
Kálahandi State 616
Mánbhum District 617
Monghyr District 617
Morbhanj State 617
Puri District. 618
Singhbhum District 618
History 618
Geology 619
Mode of occurrence of the ores . . . 619
Origin of the ores 620
Source of the manganese 620
Time of formation of the ores . . . 621

PAGE.

CHAPTER XXIX.—*concluded.*

Commercial value of the deposits, and analyses of the ores 621
Output 622
List of localities 623
1. Purána Cháibása 623
2. Kamarhatu 623
3. Matkamhatu 623
4. Tekrasai 625
5. Gitilpi 626
6. Kalenda 628
7. Tutugutu 628
8. Bistampur 629
9. Lagia 630
10. Leda Hill 630
The 24-Parganas 631

CHAPTER XXX.—**Bombay Presidency.**

Belgaum District 633
1. Munnikerri 633
2. Bhimgad 634
3. Talevádi 635
Mode of occurrence and origin . . 635
Gibbsite 639
4. Nersa 639
Bijapur District 640
Ingleswára 640
Bágalkot and Kaládgi 640
Dhárwár District 641
1. Tawargatti 642
2. Nagargali 642
Dhárwár District (Sangli State). . . . 642
Historical 642
Situation of the deposits 644
Chik-Vadvati and Kelur 644
Hamigi 646
Shirhatti 646
Nárukot State, Rewa Kántha Agency . . 646
Situation 646
Mode of occurrence 646
Time of alteration of manganese silicates to ores 647

PAGE.

CHAPTER XXX.—*concluded.*

Minerals found 647
Rocks found 648
Granite veins 649
North Kanara District 649
Pálanpur State 650
Panch Maháls District 651
History 651
Geology 652
Origin of the ores 653
Source of the manganese 654
Nature and quality of the ores . . . 654
Economic value of the deposits . . 655
Descriptions of deposits 656
Sivarájpur 656
Road section 660
Manganized slates 661
Rájpipla State 661
Ratnagiri District 661
Sátára District 661
History 661
Geology 662
Localities 662
Mode of occurrence and origin . . . 663
Nature and quality of the ores . . . 664
Economic value 664
Waral or *Mulwi* 665
1. Lingmála 665
2. Bhekauli 666
3. Chikhli 666
4. Yeruli 667
11. Khánapur 668

CHAPTER XXXI.—**Burma and Central India.**

Burma 669
Amherst District 669
Hantha-wadi District 669
Magwe District 669
Mergui District 669
Myingyan District 670
Ruby Mines District 670
Sagaing District 671

PAGE.

CHAPTER XXXI.—*continued.*

Salwin Hill Tracts 671
Taung-ngu District 671
Tavoy District 671

Central India 672
Bhopal State 672
The Dhár Forest 672
1. Hill 925 ft., Kanár 673
2. Rátagarh 674
3. Hill 888 ft. (S.W. of) 674
4. Katotia 674
5. Pola Khal 674
6. Kheria Kund 675
7. Pán Kúan 675

Gwalior State 676

Indore State 676
1. Near Kátkut 676
2. The Kanár River 677
3. Barel 677
4. Bhámar 677
Jhábua State 678
History 678
Geology 678
1. Kájlidongri 679
Mode of occurrence of ore . . . 679
Country 680
Origin 681
Nature and quality of the ores . . 682
Labour 685
Mineralogy of the deposit . . . 685
Braunite 685
Hollandite 685
Winchite and blanfordite . . . 686
Rhodonite 686
Spessartite 686
Carpholite 687
Hematite 687
Piedmontite 687
Crimson mica 687
Barytes 687
Arsenates 687

PAGE.

CHAPTER XXXI.—*concluded.*

2. Rambhápur 687
3. Amlamál 689
5. Tumdia 689
6. Pitol 689
7. Nagankheri-Mandli 690
Rewah State 690

CHAPTER XXXII.—**The Central Provinces—Amráoti and Bálághát Districts.**

Amráoti District 691
Bálághát District 691
History 691
Physical characters and geology of the manganese-ore belt 693
List of deposits 695
Nature and quality of the ores 696
Communications and transport. . . . 697
1. Chándadoh 698
2. Thirori, Ponia, and Jámrapáni (with Gáraghát) 698
Ponía 701
Thirori, North Hillocks 701
Do. West Hill 701
Do. East Hill 702
Do. South Hill 703
Jámrapáni 703
Martite and fuchsite 703
Gáraghát 704
Nature and quality of the ores . . . 704
The working of the deposit . . . 705
Output 706
3. Sonegáon 706
4. Arjoni and Jám. 706
5. Nándgáon 708
6. Ramrama 708
Constitution of the ore-band . . . 709
Nature and quality of the ores . . . 709
The working of the deposit . . . 710
Output 710
7. Katangjheri I (Government Forest) . . 710
8. Katangjheri II (Málguzári) 711
8*a*. Other localities 713

Page.

Chapter XXXII.—*concluded.*

Bakoda 713
Palæolith of manganese-ore from Budbuda . 713
9. Bálághát (Bharweli, Hirapur, and Mánegáon) . 714
History 714
Geology 714
Red and black quartzites 716
Length of the deposit 717
Width of the deposit 717
Description of the ore-band: general . . 718
The Bharweli portion 719
The Hirapur portion 719
The Mánegáon portion 720
Nature and quality of the ores . . . 721
The working of the deposit . . . 723
Output 726
9*a*. Laugur 726
10. Ghondi 727
11. Ukua, Gudma, and Samnapur . . . 727
Length and situation of the ore-band . . 727
Dip 728
Thickness of ore-band 728
'Country' 728
Character of the ore-band . . . 729
Nature and quality of the ores . . . 729
The working of the deposit . . . 730
Output 731
Other localities 732
12. Dharampur 732
13. Kanaridha 732
14. Jáirási 732
15. Kurthitola 732
Parsatola (Borapahár) 732
16. Dharpiwára 732
Bodraghát 732

Chapter XXXIII.—**The Central Provinces—Bhandára District.**

History 733
Output and labour 733
Physical characters and geology of the ore-belt . . 734
List of deposits 735

PAGE.

CHAPTER XXXIII.—*concluded.*

Nature and quality of the ores 735
Communications and transport 736
1. Kosumbah 736
Pyroxene-microcline-rock 737
2. Sitapathúr 739
Brown manganese-pyroxene 740
Manganese-micas 740
Spessartite in pegmatite 740
3. Sukli 742
4. Hatora 744
5. Miragpur. 745
6. Mohugáon Ghát 750
7. Pándarwáni 750
8. Sálebaddi 750
9. Chikhla II 750
10. Kurmura (Ponwár Dongri). 751
Manganese-ore pisolites 755
11. Chikhla I 755
A sapphirine-bearing rock 757
12. Sitasáongi 760
Ottrelite 763
13. Asalpáni I 763
13*a*. Asalpáni II (Sáya Hurki) 765
14. Pachára 767

CHAPTER XXXIV.—**The Central Provinces—Chhindwára District.**

History 770
Geology 771
List of deposits 771
Nature and quality of the ores 772
Communications and transport 773
1. Kachi Dhána 773
2. Lakhanwára 780
3. Gaimukh. 781
4. Sitapár 785
5. Bichua 789
6. Alesur 790
7. Devi 790
8. Ghoti 792

PAGE.

CHAPTER XXXIV.—*concluded.*

9. Wagora 794
10. Gowári Warhona 795
11. Dudhára 801

CHAPTER XXXV—**The Central Provinces—Hoshangábád and Jabalpur Districts.**

Hoshangábád District 802
Sontulai 802
Jabalpur District 803
History 803
Geology 805
The Sihora beds 806
Hematite-jaspers 806
Manganiferous hematite 808
Psilomelane 809
Source of the manganese 810
Formation of the ores 810
Gosalpur quartzites 811
Pyrolusite 811
Manganiferous limonite 814
Lateritoid 816
Manganese in laterite 816
Economic value of the deposits 817
List of localities 818
1. Emelia 819
2. Hardua Khurd 819
3. Kuán 819
4. Bara Chhapra 819
5. Kasai Hill 820
6. Darshani 821
7. Ponra Hill 821
8. Chhota Chhapra 822
9. Mansakra 822
10. Sihora 824
11. Mangela. 824
12. Ghogra and 13. Dhanwáhi . . . 825
14. Kurru (Kuro) 826
15. Lora Hill 826
16. Sakri 826
17. Khatola. 828
18. Paharewa 828

PAGE.

CHAPTER XXXV.—*concluded.*

19. Deori 829
20. Mangeli 829
21. Daroli 829
22. Hargarh 829
23. Bhátádon 829
24. Muret 830
25. Naigain 830
26. Chandnota 831
27. Dhangáon 831
28. Kailwás 831
29. Chindámanf 831
30. Gosalpuri 831
31. Dharampura 833
32. Hirdenagar 834
33. Marhasan 834
34. Keolári 834
35. Nargáon 834
36. Pararia (Pandaria) 834
37. Nonsar 835
38. Gangai 835

CHAPTER XXXVI.—**The Central Provinces—Nágpur District; with the Nimâr, Seoni, and Wun Districts.**

Nágpur District 836
History 836
Output and labour 839
Geology 839
Physical characters of the country . . . 840
Classification of the deposits 841
Nature and quality of the ores 842
Communications and transport 843
Group I 844
1. Kodegáon 845
Opal 847
Pyrite 847
2. Gumgáon 852
3. Rámdongri 855
Blanfordite 857
Group II 859
4. Risára 860
5. Nándgondi 861
6. Sitagondi 861

PAGE.

CHAPTER XXXVI.—*continued.*

Group III 861
7. Kándri 862
Geology of the deposit . . . 862
Slickensides grooving. . . . 867
An interesting rock 867
Nature and quality of the ores . . 867
The working of the deposit . . . 873
Output 875
Talus-ore deposits 876
8. Mansar 878
Kámthi Lady pit 883
Satára pits 884
Red ochre 885
9. Mansar Extension 891
Hematite 892
10. Parsoda 893
11. Borda 895
Group IV 896
12. Pársioni and Bansinghi. . . . 897
13. Dumri Kalán 898
14. Sátak 899
Sátak I 899
Sátak II 901
Felspathic intrusions . . . 902
15. Beldongri 904
Felspathic intrusions 905
16. Nagardhan 911
17. Nandapuri 912
18. Lohdongri 914
Spaces in the ore-body . . . 916
Braunite crystals 917
19. Kácharwáhi 922
Blanfordite, braunite, and albite . . 924
20. Waregáon 929
Spessartite crystals 930
21. Khandála 932
Manganese-laterite 933
Group V. 933
22. Mándri 934
An experiment in cleaning . . . 937

PAGE.

CHAPTER XXXVI.—*concluded.*

22A. Panchála 941
23. Mánegáon 943
24. Guguldoho 947
25. Bhandárbori 953
Group VI 954
26. Mohugáon 955
27. Páli 957
Piedmontite and piedmontite-gneiss . 958
Pyrolusite 959
28. Ghogara (Pench River) . . . 961
Piedmontite 964
The Mándvi Bir-Junapáni band . . . 965
29. Mándvi Bir 969
30. Junawáni 970
31. Junapáni 974
The Kaskuri band 974
The Bhánadeo band 976
32. Rájkota 976
Nimár District. 977
1. Chándgarh 977
2. Jámdihi Nálá 977
3. Bankuta 978
Seoni District 978
Wun (Yeotmal) District 979

CHAPTER XXXVII.—**Coorg, Goa, Haidarábád, and Kashmir.**

Coorg 980
Goa 980
History 980
The grant of concessions in Goa . . . 981
Geology 982
Origin of the ores 982
Nature and quality of the ores. . . . 983
Extent of the deposits 984
Communications and transport . . . 984
1. Fanuswádi 985
2. Dab Dabba I 986
3. Dab Dabba II 987
Other deposits 987
Vaotim 987

CHAPTER XXXVII.—*concluded.* PAGE.

Kandiapár 987
Malan, Villian, Kumári, and Kajri . . 988
Haidarábád 989
Kashmir 990

CHAPTER XXXVIII.—**Madras Presidency—Bellary District and Sandur State.**

Bellary District 991
1. The Dhárwár-Shimoga band. . . . 992
2. The Dambal-Chiknayakanhalli band . . 992
3. Sandur-Copper Mountain band . . . 992
Bellary District (Sandur State) 993
History 993
Geology : Foote's account 995
Phyllites, slates, and lithomarges . . . 996
Ferruginous quartzites 997
Basic igneous rocks 998
Granites and gneisses 998
Relations of granites and gneisses to the Dhárwárs 998
Lateritic rocks and hematitic breccias . . 999
The manganese-ore deposits 1001
List of deposits 1002
Place names 1003
Deposits visited 1004
Situation of the deposits 1004
Outcrops lateritoid and lichen-covered . . 1005
Prominence of the outcrops of manganese- and iron-ore 1005
Manganese-ore deposits apparently beds, but really surface replacements 1006
Evidence supporting the superficial replacement theory 1007
The Narayandevarkerra Ghát sections . 1007
Rámandrug Main Bed sections . . . 1008
The Rámandrug lithomarges . . . 1010
Summary of origin 1011
Depths to which the deposits extend. . . 1012
Possibility of original beds or lenses of manganese-ore 1013
Width of the deposits 1013
Length of the deposits 1014

PAGE.

CHAPTER XXXVIII.—*concluded.*

Quantities of ore 1014
Are the quantities of ore too large to have been formed by superficial replacement . . 1015
The manganese minerals present . . . 1016
Psilomelane and wad formed by replacement of phyllite 1016
Pseudo-manganite and pyrolusite in cavities . 1017
Botryoidal and lead-like psilomelane . . 1017
Braunite ? and hollandite ? 1018
Chemical composition of the ores . . . 1018
Descriptions of deposits 1020
Group I—The Rámandrug Deposits . . . 1020
1. Sannasil Haruvu (Rámandrug No. 2) . 1021
3. Rámandrug No. 4 1022
4. Rámandrug Main Bed 1024
6. Rámandrug Barracks or Manganese Cave 1025
Group II.—The Kannevihalli Deposits . . 1026
The Narihalla 1026
Group III.—The Kumáraswámi Deposits . . 1027
Group IV.—The Kámataru Deposits . . 1027
45. Yelakála Banda 1029
47. Badapatti Banda 1029
52. Alada-Marada Banda 1029
53. Durgámma Kolla 1030
55. Pillal-marada Gundu 1031
56. Karada Badasála Katevi . . . 1031
63. Hunase-marada Katevi . . . 1031

CHAPTER XXXIX.—**The Madras Presidency.**—*continued.*

Chengalput District 1032
Coimbatore District 1032
Ganjám District 1032
1. Boiráni 1034
Manganese-laterite 1036
2. Gudhiári 1036
3. Nautan-Barampur 1036
4. Mathura 1037
5. Kálikot 1037
6. Rambha 1037
Kadapah District 1038

CHAPTER XXXIX.—*concluded.* PAGE.

Karnul District 1038
Madura District 1039
Nilgiri Hills 1039
Nellore District 1040
Pudukottai State 1041

CHAPTER XL.—Madras Presidency—Vizagapatam District.

History 1042
Output and labour 1045
Physical characters of the district 1045
Geology 1046
List of deposits 1047
The nature and quality of the ores 1048
Communications and transport 1050
The Kodur Mines 1050
Output 1054
1. Garividi 1055
2. Kodur 1059
The lithomarges 1060
Yellow ochre 1061
Wad 1061
Quartz-felspar-rock 1062
Felspar-rock 1062
Vein-quartz (rose) 1062
Pyroxene-spandite-felspar-rock 1062
Spandite-rock and apatite-spandite-rock . . 1063
Mangan-fluor-apatite 1063
Pyroxene-rock 1063
Pyroxene-spandite-rock 1064
A fissure rock 1064
Apatite-felspar-spandite-rock (kodurite) . . 1064
Xenoliths of crystalline limestone . . . 1065
Chert 1065
Mangan-magnetite 1066
The ore-bodies 1066
Nature and quality of the ores 1068
The working of the deposit 1072
3. Duvvám 1073
4. Devádá 1073
Apatite 1073

PAGE.

CHAPTER XL.—*continued.*

5. Sandanandapuram 1075
Amethystine quartz 1075
Chert 1075
Lithomarges 1076
Scapolitic gneisses 1076
6. Sivarám 1077
7. Perapi 1077
Spandite-felspar-rocks 1078
Replaced microcline-rock 1078
Spandite-pyroxene-rock (rhodonite) . . . 1078
Chert and flint 1079
Scapolitic gneisses 1079
8. Itakerlapilli 1080
9. Mulagám 1081
10. Govindapuram 1081
11. Garbhám 1081
Localities of spandite-bearing rocks . . . 1087
Sections across the deposit 1087
Pegmatite and quartz crystals 1089
Chert 1089
The Palapguddi workings 1095
12. Kotakarra 1096
Kotakarra I 1096
Kotakarra II 1097
Opalized kodurite 1097
Pyroxene-scapolite-quartz-rock . . . 1097
13. Gadasám 1098
14. Avagudem 1098
15. Aitemvalsa 1100
16. Gotnandi 1101
17. Bondapilli 1101
18. Garraráju Chipurupalli (Garuja) 1101
19. Perumáli 1102
20. Rámabhadrapuram 1103
Origin of the ores 1104
Nature and quality of the ores . . . 1104
Boring operations 1106
20 *a*. Sonpuram (West Mound). 1107
The quartzites 1108
Psilomelane concretions in lithomargic rock . 1108
Banded pyroxene-quartzite 1108

PAGE.

CHAPTER XL.—*concluded.*

20 *b*. Mámidipilli (Middle Mound) 1108
Kodurite 1108
Biotite-kodurite 1109
Apatite-quartz-microcline-rock. . . . 1109
20 *c*. Bankuruvalsa (East Mound) 1110
Quartzites containing apatite, garnet, and graphite 1110
21. Táduru 1110
Manganese-pyroxenites 1111
Graphite-apatite-spandite-rhodonite-quartz-rock . 1112
Apatite-garnet-graphite-rock with manganese-ore 1112
Calcareous gneisses 1112
Biotite- and garnet-pyroxene-gneisses . . 1113
22. Chintelavalsa 1113
Scapolitic or calcareous gneisses . . . 1114
Biotite-gneiss 1114
Graphite-bearing manganese-silicate-rock . . 1114
Other localities 1115
Sandapuram 1115
Kantikapilli 1115

CHAPTER XLI.—**Maldive Islands and Mysore.**

Maldive Islands 1116
Mysore 1117
History 1117
Mode of occurrence and origin 1117
Quality 1119
Exports 1119
Bangalore District 1119
Chitaldrug District 1120
1. Sádarhalli 1122
Interesting forms of lateritoid . . 1124
Manganiferous ochre 1124
2. Dod Kittadhalli 1124
3. Madadkere 1125
4. Nirgudda Hills 1125
5. Iplára Hills 1126
6. Bodimaradi 1126
Hassan District 1126
Kadur District 1126
1. Ubráni 1126
2. Kannikalmatti (Hádikere) . . . 1126

PAGE.

CHAPTER XLI.—*concluded.*

Shimoga District 1127
History 1127
Output 1128
Physical character of the country . . 1128
Geology and origin 1129
Nature of the ores 1130
Quality of the ores 1131
Communications and transport . . . 1132
List of deposits 1133
I. The Shikarpur Group 1133
II. The Ayanur Group 1134
6. Tuppur 1134
7. Short's Block 1134
8. Kumsi 1135
Quantity of ore 1136
9. Bikonhalli 1139
10. Aladhalli 1142
III. The Shankargudda Group . . . 1142
11. Shankargudda 1143
12. Tirandur 1144
IV. The Channagiri Group . . . 1145
13. Sulekere 1145
14. Gaddikalmatti 1145
15. Buddamatti Peak 1146
16. Hoshalli 1146
17. Treasury Hill 1147
V. The Shiddarhalli Group . . . 1148
18. and 19, Bhadigund and Gangur . 1148
20. Kanjiganagutti (Shiddarhalli Main Deposit) 1149
21. Urumanjanmatti 1150
22. Ragikalvadikinakeri Bhaui Nagalagutti 1151
Tumkur District 1151
3. Sondenhalli (Solid Hill Mine) . . 1153
4. Muskondli (Rowe's Mine) . . . 1153
5. Kárekurchi (Camp Mine) . . . 1153
6. Hattyal (Temple Hill Mine) . . . 1154
7. Hárenhalli (Government Road Mine) . 1154

PAGE.

CHAPTER XLII—**North-West Frontier Province, Punjab, Rájputána, and the United Provinces,**

North-West Frontier Province 1155
Kohát District 1155
Punjab 1156
Jhang District 1156
Kángra District 1156
Lahore District 1156
Patiála State 1156
Rájputána 1157
Ajmere 1157
Alwar State 1157
Banswára State 1157
Bundi State 1158
Jodhpur State 1158
United Provinces 1158
Mirzapur District 1158

APPENDIX I.

Bibliography of Indian Manganese.

APPENDIX II.

Geographical Index.

INDEX.

LIST OF PLATES.

PART I.

PLATE 1.—Photomicrograph by reflected light of a polished and etched slice of manganese-ore from Rámdongri, Nágpur district, Central Provinces. ×16.

PLATE 2.—Mass of braunite crystals from Lohdongri, Nágpur district, Central Provinces. ½ natural size.

PLATE 3.—Pyrolusite from Páli, Nágpur district, Central Provinces. ½ natural size.

PLATE 4.—Dendrites of manganese oxide on Upper Vindhyan Sandstone, Panna, Central India. ⅕ natural size.

PLATE 5.—Fig. 1.—Stalactitic psilomelane from Garbhám, Vizagapatam district, Madras. ½ natural size.

Fig. 2.—Reniform psilomelane from Garbhám, Vizagapatam district, Madras. ½ natural size.

PLATE 6.—Fig. 1.—Psilomelane showing conchoidal fracture, Tekrasai, Singhbhum district, Bengal (J. 917). Natural size.

Fig. 2.—Mammillated psilomelane from Guguldoho, Nágpur district, Central Provinces. ½ natural size.

PLATE 7.—Spessartite crystals (trapezohedral) with interstitial quartz, on a basis of manganese-ore. From Waregáon, Nágpur district. Natural size.

PART II.

PLATE 8.—Photomicrographs:—

Fig. 1.—Opalized kodurite. Kodur, Vizagapatam district. × 16.

Fig. 2.—Opalized kodurite with some orthoclase remaining. Boiráni, Ganjám district, Madras. × 16.

Fig. 3.—Apatite-spandite-rock. Kodur. × 16.

Fig. 4.—Spandite (manganese-garnet), in psilomelane. Rámabhadrapuram, Vizagapatam district. × 23.

PLATE 9.—Banded hematite-quartzite; from Khatola, Jabalpur district, Central Provinces. The jaspery quartzite bands appear white in the photo, but are really pinkish. Natural size.

PLATE 10.—Photomicrographs:—

Fig. 1.—Fine-grained quartzite being replaced by manganese-ore. Sivarájpur, Panch Maháls district, Bombay. × 23.

Fig. 2.—Piedmontite-gneiss. Páli, Nágpur district, Central Provinces. × 23.

Fig. 3.—Piedmontite and felspar, latter altering to calcite, Ghogara, Nágpur district, Central Provinces. × 23.

Fig. 4.—Piedmontite in crystalline limestone. Ghogara. × 23.

PLATE 11.—Photomicrographs:—

Fig. 1.—Very fine-grained gondite. Jothvád, Nárukot State, Bombay. × 23.

Fig. 2.—Typical gondite. Wagora, Chhindwára district, Central Provinces. × 23.

Fig. 3.—Strained gondite by ordinary light. Rámdongri, Nágpur district, Central Provinces. × 23.

Fig. 4.—Same as fig. 3, but with nicols crossed.

PLATE 12.—Photomicrographs:—

Fig. 1.—Gondite, with garnets altering. Ukua, Bálághát district, Central Provinces. × 33.

Fig. 2.—Spessartite-rock, partially converted into manganese-ore. Mansar, Nágpur district, Central Provinces. × 23.

Fig. 3.—Rhodonite-rock. Rámdongri, Nágpur district, Central Provinces. × 23.

Fig. 4.—Pyroxene (Rhodonite ?) altering to manganese-ore. Kodur, Vizagapatam district, Madras. × 23.

PLATE 13.—Photomicrographs:—

Fig. 1.—Black manganiferous quartzite. Bálághát mine, Bálághát district, Central Provinces. × 60.

Fig. 2.—Black manganiferous quartzite. Mánegáon, Nágpur district, Central Provinces. × 16.

Fig. 3.—Vein-quartz being replaced by psilomelane. Chik Vadvati, Dhárwár district, Bombay. × 23.

Fig. 4.—Quartz-felspar-rock being replaced by manganese-ore, Garbhám, Vizagapatam district, Madras. × 23.

PLATE 14.—Piedmontite and manganese-ore nodules in a piedmontite-limestone. Around the manganese-ore nodule is a thin rim of piedmontite. ½ natural size.

PLATE 15.—Pyrolusite (dark) and calcareous tufa (light); from Pán Kuán, Dhár Forest, Central India. ½ natural size.

PLATE 16.—Map of the chief occurrences of manganese-ore in India. Scale 1 inch=256 miles.

PART IV.

PLATE 17.—Fig. 1.—Inclusions of manganese-ore and manganese-silicate-rocks in porphyritic biotite-granite. Jothvád, near Jámbughoda, Nárukot State, Bombay. February 1905.

Fig. 2.—Outcrop of manganese-ore on a quartzite ridge. Near Sivarájpur, Panch Maháls, Bombay. February 1905.

PLATE 18.—Fig. 1.—Intense folding in manganese-ore and sandy slates. Kájlidongri, Jhábua State, Central India. January 1905.

Fig. 2.—Quarrying manganese-ore at Kájlidongri. February 1905.

PLATE 19.—Sections of the manganese-ore deposit at Kájlidongri, Jhábua State. Seen in surface cross-cuts. For positions of these cross-cuts see sketch-plan.

PLATE 20.—Crumpled manganese-ore 'beds' at the Bálághát quarry. Bálághát district, Central Provinces. March 1904.

PLATE 21.—Plan of Bálághát Manganese Mine. August 1906. Scale 5 chains = 1 inch.

PLATE 22.—Hillock composed entirely of manganese-ore. Sitapár, Chhindwára district, Central Provinces. December 1903.

PLATE 23.—Manganese-quarry at Kodegáon, Nágpur district, Central Provinces. November 1903.

PLATE 24.—Geological sketch-map of Group I of the manganese deposits of the Nágpur district. Scale 1 inch = 2,000 feet.

PLATE 25.—Sketch-map of Gumgáon manganese-ore deposit, Nágpur district Scale 12 inches = 1 mile.

PLATE 26.—Fig. 1.—Kándri Hill from the east.

Fig. 2.—Level 3 of Kándri manganese-quarry.

PLATE 27.—Sections across the Kándri manganese-ore deposit along lines of section in Plate 32.

PLATE 28.—General view of the manganese-quarry at Kándri, Nágpur district, Central Provinces. January 1904.

PLATE 29.—Kándri manganese-quarry, general view. January 1904.

PLATE 30.—Working face at level 2 of the Kándri quarry. January 1904.

PLATE 31.—Excavations in the 'boulder' or 'talus'-ore deposit at Kándri. January 1904.

PLATE 32.—Sketch-plan of the Kándri manganese-ore deposit, Nágpur district, Central Provinces. Scale 1 inch = 80 yards.

PLATE 33.—Manganese-ore deposit. Mansar, Nágpur district, Central Provinces. January 1904.

PLATE 34.—Fig. 1.—The west end of the Mansar deposit. January 1904.

Fig. 2.—View showing the structure of a portion of the Mansar ore-deposit. January 1904.

PLATE 35.—Sketch-plan of the Mansar-Chárgáon ore-band. Scale 1 inch = 720 feet.

PLATE 36.—Fig. 1.—Sampling manganese-ore at Mansar.

Fig. 2.—Outcrop of manganese-ore. Sátak, Nágpur district, Central Provinces. February 1904.

PLATE 37.—Sketch-plan of the manganese-ore quarry at Beldongri, Nágpur district. February 1904. Scale 1 inch =200 feet.

PLATE 38.—Manganese-deposit at Lohdongri, Nágpur district, Central Provinces. February 1904.

PLATE 39.—Fig. 1.—Folding in the Lohdongri manganese-deposit. February 1904.

Fig. 2.—Lohdongri manganese-deposit with ore-stacks in the foreground. February 1904.

PLATE 40.—Fig. 1.—Sketch-plan of the Gowári Warhona manganese-ore deposit, Chhindwára district. Scale 1 inch=440 feet.

Fig. 2.—Plan showing the extremely variable strikes and dips of the two ore-bands at Mándri, Nágpur district. Scale 1 inch = 100 yards.

Fig. 3.—Section across the Lohdongri manganese-ore deposit, Nágpur district.

PLATE 41.—Fig. 1.—Manganese-quarry at Kácharwáhi, Nágpur district, Central Provinces. February 1904.

Fig. 2.—Manganese-ore stacked at Prince's Dock, Bombay, ready for shipping.

PLATE 42.—Excavation for pyrolusite in crystalline limestone at Páli, Nágpur district, Central Provinces. January 1904.

PLATE 43.—Geological sketch-map showing the manganese-ore deposits of the Nágpur-Bálághát area, Central Provinces. Scale 1 inch=4 miles.

PLATE 44.—General view of the workings at Rámandrug Main Bed, Sandur Hills. September 1907.

PLATE 45.—Manganese-ore body with lithomarge below; Rámandrug Main Bed, Sandur Hills. September 1907.

PLATE 46.—Cliff of manganese-ore at Durgámma Kolla, Sandur Hills. September 1907.

PLATE 47.—General view of the manganese-quarry at Kodur, Vizagapatam district, Madras. From E. N. E. January 1905.

PLATE 48.—Section at Kodur showing lithomarge, wad and manganese-ore. January 1905.

PLATE 49.—The east end of the Kodur quarry. January 1905.

PLATE 50.—Fig. 1.—North-east corner of Kodur manganese-quarry. December 1904.

Fig. 2.—Unloading manganese-ore at Garividi Railway Station, East Coast Railway. January 1905.

PLATE 51.—'Country' of wad and lithomarge at Garbhám. December 1904.

PLATE 52.—Manganese-quarry at Garbhám, Vizagapatam district, Madras. From the S. 15° E. December 1904.

PLATE 53.—Garbhám manganese-quarry from W. 40° N. December 1904.

PLATE 54.—Fig. 1.—Manganese-ore *in situ* at Garbhám. December 1904.

Fig. 2.—Manganese-ore (black) forming by replacement of quartz-felspar-rock (white) at Garbhám. December 1904.

PLATE 55.—Geological sketch map and section of the rocks near Táduru. Scale 1 inch=about ½ mile.

PLATE 56.—Map of a portion of the Vizagapatam district, Madras Presidency, showing the manganese-ore localities. Scale 1 inch=4 miles.

PLATE 57.—Manganese-ore deposit at Kumsi, Shimoga district, Mysore. September 1907.

LIST OF FIGURES IN THE TEXT.

PART I.

	PAGE.
FIG. 1.—Braunite, Kájlidongri	57
FIG. 2.— Do., do.	57
FIG. 3.— Do., Kácharwáhi	57
FIG. 4.— Do., do.	57
FIG. 5.— Do., do.	58
FIG. 6.—Braunite twin, Kácharwáhi	58
FIG. 7.— Ditto ditto	58
FIG. 8.— Ditto ditto	58
FIG. 9.—Braunite, Kácharwáhi	59
FIG. 10.— Do., Lohdongri	59
FIG. 11.—Blanfordite	126
FIG. 12.— Do.	126
FIG. 13.—Spessartite, trapezohedron, Bichua and Waregáon	172
FIG. 14.— Do., striated trapezohedron, Chárgáon	172
FIG. 15.— Do., trapezohedron and dodecahedron, Waregáon	172
FIG. 16.— Do., dodecahedron, Kulu and Kachi Dhána	173
FIG. 17.— Do., trapezohedron and hexoctahedron, Bhui Hurki and Waregáon	173
FIG. 18.— Do., trapezohedron, dodecahedron, and hexoctahedron, Waregáon	173
FIG. 19.— Do., trapezohedron, composed of vicinal hexoctahedral faces, Waregáon	173
FIG. 20.— Do., octahedron	173

PART II.

FIG. 21.—Ideal section across a syncline of manganiferous rock	317
FIG. 22.—Typical section of laterite. Talevádi, Belgaum district	384

PART III.

FIG. 23.—Diagram showing the variation in the prices of manganese-ore at United Kingdom ports since 1890	417
FIG. 24.—Diagram showing the variation in the prices of manganese-ore at United Kingdom ports since December 1904	419
FIG. 25.—Diagram showing the annual manganese-ore production of the different districts of the Central Provinces	441

PAGE.

FIG. 26.—Diagram showing the annual manganese-ore production of the different provinces of India since 1892 . . . 444
FIG. 27.—Diagram showing the manganese-ore production since 1890 of the four leading countries 452
FIG. 28.—Prospecting an outcrop on low ground 551
FIG. 29.— Ditto ditto along a ridge 552
FIG. 30.—Quarrying a thick ore-band of moderate dip in a hill . . 555
FIG. 31.—Mining or quarrying a thick ore-band of steep dip in a hill . 557
FIG. 32.—Quarrying a thick ore-band cropping out of low ground . 559
FIG. 33.—A thin ore-band cropping out of low ground . . . 560
FIG. 34.—Scattered ore-bodies in lithomarge 561
FIG. 35.—A lateritoid capping 563
FIG. 36.—A detrital or talus-ore eposit 564
FIG. 37.—Systematic plan of working detrital deposits . . . 565

PART IV.

FIG. 38.—Map of the Sivarájpur manganese area 653
FIG. 39.—Quartzite partly replaced by manganese-ore . . . 658
FIG. 40.—Map of the Thirori manganese-ore bands. Scale 1 inch = 1 mile 699
FIG. 41.—Plan and section of a portion of the Arjoni-Jám manganese-ore deposit 707
FIG. 42.—Map of the Bálághát manganese-ore deposit. Scale 1 inch = 1 mile 715
FIG. 43.—Round nodules of red quartzite in manganese-ore; at Bálághát 716
FIG. 44.—Section across the Hirapur portion of the Bálághát manganese-ore deposit 720
FIG. 45.—Sketch-plan of the Miragpur manganese-ore occurrences . . 746
FIG. 46.—Section across the Gárkár-Bhúnga portion of the Asalpáni manganese-ore deposit 764
FIG. 47.—Sketch-plan of the Gaimukh and Lakhanwára deposits . . 782
FIG. 48.—Banded hematite-jasper showing slaty cleavage . . . 808
FIG. 49.—Sketch-plan of Kodegáon Mine 1 846
FIG. 50.— Ditto ditto Mine 2 848
FIG. 51.—Diagram of the S. E. end of the Kándri manganese-ore body . 863
FIG. 52.—Diagrammatic section across South Hill, Kándri, at Level 2 . 863
FIG. 53.—Anticlinal overturn of back of ore-body near level 3, Kándri . 863
FIG. 54.—Diagram illustrating the faulting of East Hill, Kándri . . 865
FIG. 55.— Do. to illustrate shape of Kándri manganese-ore body . 866
FIG. 56.—Section in detrital deposits at Kándri 877
FIG. 57.— Ditto ditto 878
FIG. 58.—Sketch-section across the Mansar deposit at its highest point . 881

PAGE.

FIG. 59.—Overturn in beds of manganese-ore at Mansar . . . 882
FIG. 60.—Section across the Kámthi Lady Pit, Chárgáon . . . 883
FIG. 61.— Ditto one of the Sátára Pits, Chárgáon . . . 884
FIG. 62.—Lenticularly expanding and contracting band of gondite, Mansar 885
FIG. 63.—Section seen in a pit on the Sátak ore-mound . . . 901
FIG. 64.—Intrusion of felspar-rock into the ore-body at Beldongri . 906
FIG. 65.—Sketch-plan of the Nandapuri workings 912
FIG. 66.—Rough sketch-plan of the Lohdongri manganese-ore deposit . 914
FIG. 67.—Diagram of a sharp fold in the manganese-ore layers at Lohdongri 915
FIG. 68.—The course of two 'ore-beds' at C (see plan of Lohdongri) . 916
FIG. 69.—Sketch-plan of ore-bands and hills at Mándri . . . 934
FIG. 70.—Slickensides-grooving in quartzites at Mándri . . . 935
FIG. 71.—Map showing the position of the Mándri, Panchála, Mánegáon, Guguldoho, and Bhandárbori manganese-ore deposits. Scale 1 inch = 2 miles 943
FIG. 72.—Plan showing local twisting of strike of ore-band at Mánegáon 943
FIG. 73.—Sketch-plan of the Mohugáon manganese-ore deposit . . 956
FIG. 74.—Section showing manganese impregnations in limestone . . 963
FIG. 75.—Diagrammatic sketches of some manganese-ore nodules . . 963
FIG. 76.—Section across the Rámandrug Main bed deposit . . . 1006
FIG. 77.—Piece of altered magnetite-slate 1009
FIG. 78.—Rough cross-section of Rámandrug No. 4 deposit . . . 1022
FIG. 79.—Geological sketch-map of the Kodur Mines, Vizagapatam district 1051
FIGS. 80 AND 81.—Alternative interpretations of structure along the line of section XY in fig. 79 1053
FIG. 82.—Rough sketch-plan of the Kodur Quarry (January 1905) . 1060
FIG. 83.—Section seen in a pit at Perapi 1078
FIG. 84.—Sketch-plan of Garbhám 1082
FIG. 85.—Quartz-felspar-rock undergoing replacement by manganese oxide 1085
FIG. 86.—Felspar-rock undergoing replacement by manganese-ore and ochre 1086
FIG. 87.—Section across the middle of the Garbhám deposit . . 1087
FIG. 88.— Ditto the Garbhám deposit to east of middle . . 1088
FIG. 89.—Diagram of anticlinal fold (A) affecting the Garbhám deposit west of middle 1088
FIG. 90.—Section seen in the east end of the Garbhám quarry . . 1089
FIG. 91.— Do. across one of the Sonpuram pits 1107
FIG. 92.— Do. across hill near Chintelavalsa 1114

LIST OF TABLES.

PART I.

PAGE.

TABLE 1. Physical constants of the manganese-iron group of elements . 16
TABLE 2. List of known manganese minerals with their chief properties 23
TABLE 3. List of Indian manganese minerals 34
TABLE 4. List of certain minerals associated with the Indian manganese-ore deposits 35
TABLE 5. Faces observed on Indian braunites 62
TABLE 6. Ditto foreign braunites 62
TABLE 7. Analyses of Indian braunites 63
TABLE 8. Ditto pyrolusites 82
TABLE 9. Comparison of properties of manganite, pseudo-manganite, and pyrolusite 86
TABLE 10. Analyses of hollandite 93
TABLE 11. Ditto in terms of manganates . . 94
TABLE 12. Do. of Indian psilomelanes 100
TABLE 13. Ditto ditto in terms of manganates . 101
TABLE 14. Do. (in terms of manganates) of psilomelane obtained by calculation 112
TABLE 15. Analyses of psilomelane obtained by calculation . . . 114
TABLE 16. Properties of the yellow and brown pyroxenes associated with the gondite series 136
TABLE 17. Analyses of Indian manganese-garnets 168
TABLE 18. Optical properties of pink micas 198
TABLE 19. A key to the identification of the black, and dark-grey, iron, manganese, and chromium minerals 226
TABLE 20. A key to the identification of the black, dark-grey, and bronze-coloured, manganese-ores 228

PART II.

TABLE 21. Classification of Indian occurrences of manganese-ore and manganese minerals according to their geological position 240
TABLE 22. Classification, according to origin, of the manganese-ores associated with the Dhárwár rocks 305
TABLE 23. Classification of the deposits of lateritic manganese-ores . 385
TABLE 24. Analyses of lateritic ores 389

PART III.

TABLE 25. List of vernacular names for manganese-ore . . . 412
TABLE 26. Price of manganese-ore per long ton in 1886 . . . 414

PAGE.

TABLE 27. Variation in the price of manganese-ore *c. i. f.* at United Kingdom ports 415
TABLE 28. Detailed production of the Vizagapatam district . . 434
TABLE 29. Production of the Madras Manganese Company (Vizagapatam district) during 1906 435
TABLE 30. Detailed production of the Bálághát district . . . 436
TABLE 31. Ditto Bhandára do. . . . 437
TABLE 32. Ditto Chhindwára do. . . . 438
TABLE 33. Ditto Nágpur do. . . . 439
TABLE 34. Ditto remaining provinces . . . 442
TABLE 35. Annual production of manganese-ore in India, by districts, states, and provinces 443
TABLE 36. Production of manganese-ore as given in the 'Mineral Production of India' 445
TABLE 37. Total production of each district, state, and province . . 446
TABLE 38. List of Indian deposits from which over 100,000 tons of manganese-ore have been extracted up to the end of 1906 447
TABLE 39. World's production of manganese-ores from 1890 to 1906 . 450
TABLE 40. World's production of manganiferous iron-ores from 1890 to 1906 453
TABLE 41. World's total production of manganese-ores and manganiferous iron-ores from 1890 to 1906 454
TABLE 42. Exports of Indian manganese-ore from 1892 to 31st March 1907 455
TABLE 43. Distribution of exported Indian manganese-ore for the years 1895-1896 to 1906-1907 456
TABLE 43A. Detailed production of manganese-ore in India in 1907 . 459
TABLE 44. Rates for coolie labour 468
TABLE 45. Daily number of workers employed on the manganese quarries from 1895 to 1907 470
TABLE 46. Daily number of workers employed in the manganese quarries of Bombay and the Central Provinces, from 1900 to 1907 471
TABLE 47. Rates per ton for carting manganese-ore 476
TABLE 48. Rates for the carriage of manganese-ore to the ports over Indian railways 479
TABLE 49. Rates for the carriage of manganese-ore to Mormugáo by the Southern Mahratta Railway 480
TABLE 50. Summary of costs per ton of delivering Indian manganese-ore *c. i. f.* at English and Continental ports . . . 486
TABLE 51. Average cost of Indian manganese-ore delivered *c. i. f.* at English and Continental ports 487

PAGE.

TABLE 52. Comparison of cost of delivering Brazilian, Russian, and Indian manganese-ore *c. i. f.* in London 489
TABLE 53. Royalty, in annas per ton, levied in certain Native States and Zemindari Lands 490
TABLE 54. Royalties in annas per ton leviable on Central Provinces manganese-ore at $2\frac{1}{2}\%$ on pit's mouth value . . . 492
TABLE 55. Analyses of manganese-ores and manganiferous iron-ores from Singhbhum, district, Bengal 501
TABLE 56. Analyses of manganese-ores from Panch Maháls, Bombay . 501
TABLE 57. Ditto Sátára district, Bombay . 502
TABLE 58. Ditto Jhábua State, Central India 502
TABLE 59. Ditto Bálághát district, Central Provinces . . . 503
TABLE 60. Ditto Bhandára district, Central Provinces . . . 503
TABLE 61. Ditto Chhindwára district, Central Provinces . . 504
TABLE 62. Analyses of samples of manganese-ores from the Nágpur district, Central Provinces 505
TABLE 63. Analyses of hand-specimens of manganese-ores from the Nágpur district, Central Provinces 506
TABLE 64. Analyses of manganese-ores, manganiferous iron-ores, and iron-ores, from the Jabalpur district, Central Provinces . 507
TABLE 65. Analyses of samples of manganese-ores and ferruginous manganese-ores from the Vizagapatam district, Madras . 508
TABLE 66. Analyses of hand-specimens of manganese-ores (some ferruginous) from the Vizagapatam district, Madras . . 508
TABLE 67. Average analyses of the manganese-ores of the Vizagapatam district, as supplied by the Vizianagram Mining Company 509
TABLE 68. Average analyses of the ferruginous manganese-ores of the Vizagapatam district, as supplied by the Vizianagram Mining Company 509
TABLE 69. Range of analyses of manganese-ores and manganiferous iron-ores from the different districts and provinces of India . 510
TABLE 70. Mean of analyses of manganese-ores and manganiferous iron-ores from the various districts and provinces of India . 512
TABLE 71. Analyses of Indian manganese-ores for which buyers stipulate when making contracts 514

PAGE.

TABLE 72. Limits of analyses of cargoes of manganese- and manganiferous iron-ores landed at Middlesborough during the 10 years 1897 to 1906 517
TABLE 73. Mean of ditto 518
TABLE 74. Limits of analyses of Indian ores in Table 72 arranged according to probable source. 519
TABLE 75. Mean of ditto . . . Table 73 . . . 519
TABLE 76. Analyses of the manganese-ores of the world . . . 520
TABLE 77. Value of the Indian manganese-ore production as reported in the Statistics of Mineral Production . . . 530
TABLE 78. Export values of the manganese-ore produced in the Madras Presidency from 1892 to 1906 533
TABLE 79. Export values of the manganese-ores produced in the Central Provinces from 1900 to 1906 534
TABLE 80. Export values of the manganese-ores produced in Bengal, Bombay, Central India, and Mysore, from 1903 to 1906 . 535
TABLE 81. Export values in rupees, *f. o. b.* at Indian ports, of manganese-ore produced in the various provinces of India from 1892 to 1906 535
TABLE 82. Export values in Sterling *f. o. b.* at Indian ports, of the manganese-ore produced in the various provinces of India from 1892 to 1906 536
TABLE 83. Values in Sterling *c. i. f.* at destination of the manganese-ore produced in India from 1900 to 1906 536
TABLE 84. Values of the 8 chief mineral products of India for the years 1903 to 1906 537
TABLE 85. Average prices per ton, at Pittsburg, United States of America, of 80% ferro-manganese for the years 1901 to 1907 540
TABLE 86. Value of the Indian manganese-ore production from 1892 to 1906, when converted to ferro-manganese . . . 540
TABLE 87. Depths to which Indian manganese-ore deposits extend . 547
TABLE 88. List of uses of manganese 581
TABLE 89. Analyses of native-made irons 596
TABLE 90. Available oxygen and manganese peroxide present in pyrolusite, psilomelane, and hollandite 598
TABLE 91. Prices of manganese-ores sold for peroxide 599
TABLE 92. Quantity and value of the Canadian manganese-ore production from 1893 to 1905 601

THE

MANGANESE-ORE DEPOSITS OF INDIA.

SYNOPSIS OF PARTS I, II, AND III.

SYNOPSIS OF PARTS I, II, AND III.

This synopsis is for the purpose of directing attention to the more important of the results of the work carried out on the Indian manganese-ore deposits, and for giving brief accounts of the more important theories. The results are summarized chapter by chapter: but it has not been considered necessary to summarize Part IV, in which are contained the descriptive accounts of the various deposits; nor all the chapters in the other parts. For Part IV and the chapters not summarized, the lists of contents given at the beginning of this work are sufficient.

[PART I.]

[INTRODUCTION AND MINERALOGY.]

[CHAPTER II.]

The effect of the presence of manganese on the colour of a mineral is considered, and attention drawn to the remarkable colour change that may be produced into a mineral by the presence in it of a small percentage of this element sometimes even of a trace. Whilst manganese minerals may exhibit almost any colour, the colours that seem to be

specially characteristic of the presence of manganese are various shades of red, pink, and lavender. A list is given enumerating all the well-defined minerals containing either a considerable proportion of manganese, or sufficient of this element to produce a marked change in the characters of the mineral, especially of the colour. The number of such minerals is 156. Of these minerals 44—enumerated on page 34—have been found in India, the identifications of 11 of them being doubtful, and really indicating the already-known mineral to which the Indian one bears the closest resemblance. Later examination of these may in some cases show that they are different to any previously known minerals. During the examination of the minerals found in the Indian manganese deposits several new varieties and species have been discovered. These are as follows :—

Oxides :—
Vredenburgite,
Sitaparite,
Manganates :—
Hollandite,
Beldongrite,
Pyroxenes :—
Blanfordite,
Amphiboles :—
Winchite,
Juddite,

whilst two new names—*spandite* and *grandite*—have been introduced to designate certain garnets. Accounts of these various minerals are given in the succeeding chapters. In addition to the minerals that have been sufficiently investigated to be named, one manganiferous phosphate and three arsenates, all probably new, have been found. Some of the manganiferous micas found are also probably new varieties.

[CHAPTER III.]

Oxides.

Vredenburgite.—This is a bronze-tinted dark steel-grey mineral; roughly speaking it is as magnetic as magnetite, sometimes even

exhibiting polarity. H = 6·5. G = 4·74 to 4·85. Its composition seems to be best expressed by the formula $3Mn_3O_4.2Fe_2O_3$. It has been found at Beldongri, Nágpur district, Central Provinces; and Garividi, Vizagapatam district, Madras.

Sitaparite.—This is another dark bronze-grey mineral, easily distinguished from vredenburgite by the fact that it is only slightly magnetic. Its composition is complex and may be represented somewhat doubtfully by the formula $9Mn_2O_3.4Fe_2O_3.MnO_2.3CaO$. It is found at Sitápar, Chhindwára district, Central Provinces.

Braunite.—Measurable crystals of this mineral have been found at five localities in India, namely, Kájlidongri in Central India, and Kácharwáhi, Lohdongri, Kodegáon, and Sitapár, in the Central Provinces. Ten figures of crystals are given illustrating the following 10 forms, of which the last three are ones not previously recorded on this mineral:—(001), (100), (110), (101), (111), (421), (423), (427), (201), and (865). The total number of forms that has been recognized on braunites from all parts of the world is 16. The mean value of the fundamental angle pp' is determined as 77°21′. This being so close to the value 77°19′ found by Flink for Swedish braunites, the latter, corresponding to a value of 0·99220 for the vertical axis $\dot{c}$, is accepted as the mean value for braunite; but it is probable that there is a real variation, between narrow limits, of the value of this angle owing to differences between the composition of different crystals. The composition of the mineral is discussed at some length, the previous literature on the subject being reviewed. The conclusion arrived at is that the formula of this mineral can be represented in the most general way as:—

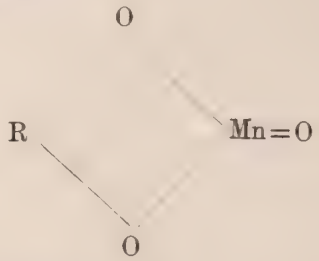
$$m\mathrm{RMnO_3} + n\mathrm{RSiO_3},$$

in which R is to a large extent Mn, but may be partly Fe, Ca, Ba, etc.; and in which the ratio $m : n$ varies between 4 : 1 and 3 : 1. The three chief varieties correspond to the three formulæ:—

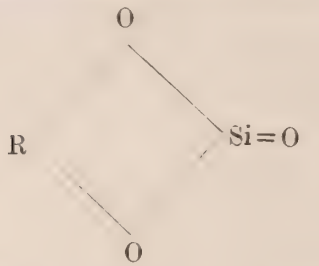
$$4Mn_2O_3 + MnSiO_3$$
$$7Mn_2O_3 + 2MnSiO_3$$
$$3Mn_2O_3 + MnSiO_3.$$

The isomorphism of the different varieties of this mineral is explained

as due to the Mn_2O_3 group being probably a manganite with the following structural formula :—



fsomorphous with the structural formula of a metasilicate :—



By the admixture in different proportions of molecules with different elements as R, all the varieties of braunite can be obtained, the only limits to the proportion in which these molecules may be mixed, so that the mineral is still braunite, being that the ratio of $RMnO_3$ to $RSiO_3$ must not lie outside the limits 4 : 1 and 3 : 1, and that the number of molecules with Mn for R must be largely predominant.

Manganite.—Several occurrences are known in India of minerals with the crystallographic form of manganite; but none of them seem to be fresh. Some have been completely converted into pyrolusite, whilst some of them bridge the gap, as regards both chemical composition and physical properties, between pyrolusite and manganite. For these forms the name *pseudomanganite* is introduced.

[CHAPTER IV.]

Manganates and Carbonates.

Hollandite.—The original notice of this new mineral is contained in the *Transactions of the Mining and Geological Institute of India*, Vol. I,

p. 76, (1906). It is to be regarded as the crystalline form of psilomelane, and is a crystalline manganate of the general formula $mR''_2MnO_5 + nR'''_4(MnO_5)_3$, in which R″ may be Mn, Fe, Ba, Ca, Mg, K_2, Na_2, Co, Ni, Cu, and H_2, and R‴ may be Mn, Fe, and Al. The most important of the elements replacing the R″ are usually Mn, Ba, K_2, and H_2, named in order of importance, and of those replacing R‴, Fe and Mn. An analogous mineral is the one found in Arizona and named coronadite. It is chiefly a lead-manganese manganate, and is probably isomorphous with hollandite. The crystallography of hollandite has not yet been properly worked out, although definite crystals are available. The crystals are found at Kájlidongri in Central India; but the mineral has also been found at Sitapár, Bálághát, Junawáni, and other localities in the Central Provinces, and is largely exported from two of the mines, namely Sitapár and Bálághát. It varies in colour from light grey to almost black, has a hardness of 6 on crystal faces and of 4 on fracture surface. The specific gravity of the mineral from the type locality, Kájlidongri, is about 4·95, whilst the value for that from Sitapár is only 4·70.

Psilomelane.—This is the most widely spread and abundant ore of manganese found in India. Several analyses are given and it is shown that the supposition first put forward by Laspeyres that psilomelane may be regarded as derived from a hypothetical acid of the composition H_4MnO_5 is in all probability correct. The general formula is the same as that already given for hollandite, and the relative importance of the constituents replacing R″ and R‴ is about the same. An example is given of the way in which an analysis of a piece of ore composed mainly of a mixture of psilomelane and braunite can be recalculated into terms of the mineralogical composition of the ore.

Beldongrite.—This is the name given to a black pitch-like mineral that is probably to be regarded as the product of alteration of spessartite. After eliminating other substances from the one analysis made, the balance is found to correspond very closely to the formula $6Mn_3O_5.Fe_2O_3.8H_2O$. If this be the true composition of the mineral, then there is no doubt that it is a distinct mineral, to be regarded as closely allied to psilomelane, but with ferric oxide and water in addition to the Mn_3O_5, which can be regarded as Mn_2MnO_5;

but it cannot be regarded as certain that this is really a distinct mineral until the formula has been confirmed by further analytical work. The mineral was found at Beldongri, Nágpur district, Central Provinces; and what looks like the same substance occurs at Chárgáon in the same district.

Wad.—The term wad is used to designate all the non-crystalline and indefinite mixtures of manganese and other oxides that do not correspond to a definite formula, such as that of psilomelane.

[CHAPTER V.]

Silicates: Pyroxenes and Amphiboles.

Blanfordite.—The original account of this mineral is given in the *Transactions of the Mining and Geological Institute of India*, Vol. I, p. 78, (1906). It is a manganiferous pyroxene of the following striking pleochroism :—

a = rose-pink,
b = bluish lilac,
c = sky-blue.

The foregoing corresponds to the mineral found at the original locality, Kácharwáhi, Nágpur district, Central Provinces. Similar but less marked pleochroism is seen in pyroxenes from Rámdongri in the Central Provinces, Kájlidongri in Central India, and Nárukot in Bombay.

Notes on *mangan-hedenbergite* and minerals that may be *schefferite* and *urbanite* are also given.

Rhodonite.—The occurrence, characters, alteration, and use of this mineral are noticed.

Of *manganese-amphiboles* three varieties are noticed, namely one that may be *dannemorite*, and two new varieties, *winchite* and *juddite*.

Winchite.—The original account is given in *Rec. G. S. I.*, XXXI, p. 235, (1904). The mineral is blue in hand-specimen and is distinguished by its zoned structure and the following pleochroism :—

a = pinkish lilac,
b = pale lilac,
c = blue.

Chemical analysis shows the mineral to be allied to both tremolite and richterite. It is found in schistose rocks at Kájlidongri and is of metamorphic origin.

Juddite.—The chief diagnostic of this mineral is the following beautiful pleochroism :—

a = carmine,
b = blue with a lilac tinge, to pale green with a lilac tinge,
c = orange.

It is found with blanfordite in a braunite-albite rock at Kácharwáhi, and is probably of igneous origin. It is further distinguished as being one of the rare amphiboles with the optic axial plane at right angles to the plane of symmetry of the mineral, instead of coinciding with it.

[CHAPTER VI.]

Silicates : Garnets.

Manganese-garnets are very abundant in some of the Indian manganese-ore deposits. The varieties found in the Central Provinces are grouped under the name spessartite, and the series of rocks in which they occur, which is of metamorphic origin, is called the *gondite series*. Many good crystals of this spessartite have been found and eight examples are figured. The chief form is the trapezohedron. The localities for the best crystals are Jothvád, Hatora, Bichua, Gaimukh, Chárgáon, Sátak, Waregáon, and Kulu, all except the first and last being in the Central Provinces.

Spandite.—The garnets found in the *kodurite series*—of igneous origin—in the Vizagapatam district, Madras, are found to be roughly intermediate between spessartite and andradite in composition. For convenience of use they have therefore been designated *spandite*, a contraction of spessart-andradite. Spandite has not yet been found exhibiting definite crystal faces, being always in more or less rounded granules.

Grandite.—Rocks of the kodurite series seem also to occur at Boiráni in the Ganjám district of Madras. But the garnet is found to differ in composition from that of Vizagapatam and to be a

manganiferous variety intermediate between grossularite and andradite. On the same principle this garnet should be called *mangan-grandite*, or more conveniently *grandite*.

Calderite.—This name was proposed by Piddington for a rock from the Házáribágh district, Bengal, composed of a mixture of quartz and garnet, in which the quartz may sometimes be absent. The analysis given indicates a garnet of the composition $3MnO.Fe_2O_3.3SiO_2$, which is not one of the six recognized varieties. It is not certain, however, that such a garnet really exists.

[CHAPTER VII.]

Silicates: Epidotes, Micas, etc.

Piedmontite.—Manganiferous epidotes have been found at severa localities in the Central Provinces, and at Kájlidongri and Jothvád. None of them have been really critically examined, so that it cannot be said at present if all of them are to be regarded as piedmontite, or if some of them are *mangan-epidote*, the distinction between these two minerals being a question of sign. Throughout this Memoir all these minerals are referred to as piedmontite. The only examples showing well-marked crystal forms come from Jothvád.

Micas.—A very large number of micaceous minerals has been found in the Indian manganese-ore deposits, especially those of the gondite series. None of them have been quantitatively analysed, so that it is not at present possible to say if they all fall under already-described varieties, or not. Judging from their pleochroism schemes I should say that some of them are probably new varieties, whilst some fall under *alurgite* and *manganophyllite*. Some may be *mangan-chlorite*. At two localities—Chikhla and Bálághát—*ottrelite* has been found in phyllites and mica-schists.

[CHAPTER VIII.]

Titano-silicates, Niobates, Phosphates, and Tungstates.

The rare manganiferous variety of sphene known as *greenovite* occurs in granitic veins traversing the manganiferous rocks at Jothvád in Nárukot.

Manganapatite.—This has been found in abundance at two localities in the Vizagapatam district, in rocks of the kodurite series. That found at Kodur is lilac and that found at Deváda sea-green.

A manganesian phosphate of oil-green colour occurs at Chárgáon in the Nágpur district. It is probably a new species.

[CHAPTER IX.]

Associated Non-Manganiferous Minerals.

A list of some 20 non-manganiferous minerals found in association with the manganese-ores is given. The most interesting of them are the three arsenates to which reference has already been made, and barytes, which has been found at several localities in small quantities in association with the deposits of the gondite series.

[CHAPTER X.]

The Identification of Manganese Minerals.

In this chapter some hints are given as to the points to be noticed in distinguishing the Indian manganese minerals one from another.

[PART II.]

[GEOLOGY.]

Mode of Occurrence and Origin.

[CHAPTER XI.]

General.

A brief account is given of the Archæan rocks of the Indian Peninsula, and the following classification of the Indian pre-Cambrian rocks is adopted :—

I. Archæan :—

1. The oldest gneisses (Bengal Gneiss).
2. The schistose gneisses and the Dhárwárs.
3. The plutonic intrusives, such as the Bundelkhand granite and the charnockite series.

II. Purána :—

The Bijáwars, Kadapahs, Vindhyans, etc.

The occurrences of manganese-ores and minerals in India are classified according to the age of the rocks with which they are associated, although they have in many cases been formed by secondary processes subsequently to these associated rocks. All the ores at present being worked are associated with rocks of Archæan age, with two exceptions. Those of Archæan age are divided into three main groups :—

1. Those associated with the rocks of the kodurite series of the Vizagapatam and Ganjám districts, Madras.
2. Those associated with the rocks of the gondite series of the Central Provinces, and Jhábua, in Central India.
3. Those occurring as lateritoid on the outcrops of rocks of Dhárwár age, in Belgaum, Jabalpur, Mysore, Sandur, and Singhbhum.

The two exceptions are those ores that can be regarded as occurring in true laterite—though this is very closely related to lateritoid,—

as in Goa, Belgaum, and Jabalpur ; and possibly the ores being worked in Baluchistán ; but about the latter deposits I have no trustworthy information.

[CHAPTER XII.]

The Kodurite Series of Vizagapatam and Ganjám.

The rocks of the Vizagapatam district are divided into the following groups :—

1. Kodurite series.	Igneous.
2. Charnockite series.	
3. Gneissose granite.	
4. Calc-gneisses.	Metamorphic.
5. Khondalite series.	
6. Contact products of 2 and 5.	

The evidence obtained is held to point to the intrusive nature of the rocks of the kodurite series with regard to the khondalite series and the calc-gneisses. The evidence in favour of the igneous origin of the kodurite series is summed up as follows :—

1. The mineralogical and chemical composition of the rocks, which could be explained only with difficulty on any other hypothesis.
2. The signs of magmatic differentiation found.
3. Some masses of crystalline limestone at Kodur supposed to be xenoliths.
4. A pegmatoidal variety of the kodurite series at Rámabhadrapuram.
5. The varying horizon that the rocks of this series occupy in the succession of calc-gneisses and khondalites.
6. The fact that in two cases, Chintelavalsa and Táduru, they are also associated with rocks that probably belong to the charnockite series.

The typical rock of this series is that designated *kodurite* after the Kodur mine. It is composed of potash-felspar (orthoclase), manganese-garnet (spandite), and apatite, in varying proportions. Other members of the series receive their names in accordance with the

additional minerals present in the rock. Some of these varieties are more acid and some of them more basic than the typical kodurite. The following is a classification of them according to their basicity :—

Quartz-orthoclase-rock. Apatite-quartz-orthoclase-rock. Quartz-kodurite in part.	Acid.
Quartz-kodurite in part. Orthoclase-rock.	Intermediate.
Kodurite. Pyroxene-kodurite. Biotite-kodurite.	Basic.
Spandite-rock. Apatite-spandite-rock. Pyroxene-spandite-rock. Manganese-pyroxenites. Graphitic manganese-pyroxenites.	Ultra-basic.

At Kodur, the more basic members of the series, such as spandite-rock, occur as large patches and streaks surrounded by zones of less basic composition, such as kodurite, in a general matrix of quartz-felspar-rock or felspar-rock, the most acid members of the series. Such an arrangement is just such as one would expect had magmatic differentiation of the magma set in prior to its eruption. And such is taken as the explanation of the mode of association of these various rocks.

As the result of the analysis of two specimens of opalized kodurite from Kotakarra in the Vizagapatam district, and Boiráni in the Ganjám district, the mineralogical compositions of the unaltered rocks have been calculated as follows :—

	Kotakarra kodurite.[1]	Boiráni kodurite.
Apatite	3·36	2·62
Orthoclase	41·29	57·80
Albite	..	2·79
Garnet	55·04	36·55
TiO_2	0·29	0·24
CuO	0·02	trace
	100·00	100·00
Specific gravity	3·23	2·92

[1] The apatite is lower in this analysis than it would have been on a large sample of the rock; for the apatite is arranged in bands in the rock, and the apatite bands were scarce in the specimen analysed.

[CHAPTER XIII.]

The Kodurite Series—*concluded.*

The alteration of the series and the formation of the manganese-ores.

In this section evidence is given to show that the manganese-ores were formed subsequent to the eruption of the kodurite series by the action of aqueous solutions percolating through the masses of rock. The various changes brought about are supposed to have been effected by solutions containing dissolved carbon dioxide and alkaline carbonates. The key to the changes that have taken place lies in the following equation :—

$$K_2O.Al_2O_3.6SiO_2 + CO_2 + 2H_2O = 2H_2O.Al_2O_3.2SiO_2 + K_2CO_3 + 4SiO_2.$$

Orthoclase. Kaolin.

By this reaction the felspar gets converted into lithomarge or kaolin, and a solution of colloidal silica in water containing alkaline carbonates and carbon dioxide results.

In many cases, probably owing to attack by these carbonated alkaline waters, manganese has been taken into solution from the garnets and pyroxenes, doubtless as bicarbonate, and carried to another part of the rock-mass. Here, probably owing to the saturation of the solution with manganese bicarbonate, the manganese has been deposited so as to replace all the minerals of the rock, except those containing manganese, which have in some cases remained fresh and unaltered, and in others have also been broken up. Thus the manganese-ore resulting from the replacement of kodurite consists sometimes of compact psilomelane studded with bright red or orange spandite-garnets, and at other times entirely of manganese-ore. In cases where the mineral replaced by the manganese-ore is felspar the reaction can be explained as follows :—

$$MnH_2(CO_3)_2 + 2(K_2O.Al_2O_3.6SiO_2) + O$$

Orthoclase.

$$= 2K_2CO_3 + 2Al_2O_3 + 12SiO_2 + H_2MnO_3.$$

The result of the actions represented in both the equations given above is the passage into solution of silica in the colloidal form. This has often been subsequently deposited in the form of either chert or opal, with a complete replacement of the rock where the former is deposited and a partial replacement where the latter is deposited.

In cases where the mineral replaced by the attacking solutions is spandite, the action can be represented as taking place according to the following equation, when we must suppose that the manganese derived from the garnet is added to that deposited from the solution.

$$2[3(Ca,Mn)O.(Fe,Al)_2O_3.3SiO_2]^* + 3MnH_2(CO_3)_2 + 3O_2 + 6H_2O =$$

Spandite.

$$= 6\,(MnO_2.H_2O) + 2(Fe,Al)_2O_3 + 3CaH_2(CO_3)_2 + 6SiO_2.$$

The ores formed by these secondary processes can be divided into three groups :—

1. Those formed by the replacement of rocks, such as quartz-felspar-rocks, not originally containing manganese. In this case all the manganese is of external origin.

2. Those formed by the replacement of rocks, such as kodurite, that contain a fair amount of manganese silicate, the manganese of the latter being added to that of the attacking solutions. In this case the larger proportion of the manganese is of external origin.

3. Those formed by the decomposition *in situ* of rocks composed almost entirely of manganese silicates, to the manganese of which a further portion, brought by the attacking solutions, is added. In this case about half of the manganese is of external origin.

The ores formed according to these three methods are shown below :—

1. Pyrolusite and psilomelane.
2. Psilomelane with some braunite.
3. Psilomelane with braunite as specks and patches.

Depths to which the ores extend.

The solution of this question seems to depend on the determination of the depths at which kaolinization takes place. Of the two reagents, carbon dioxide and sulphuric acid, by which the kaolinization might have been effected, carbon dioxide is regarded as the more probable. The conclusion reached is that kaolin is formed near the surface rather than at considerable depths ; in fact, according to Lindgren, kaolin is found in the zone of oxidation, giving way to sericite at greater depths. The formation of the manganese-ores and the kaolin must have taken place since the rocks of the kodurite series came into the zone of weathering, as defined by Van Hise. The depth to which the zone of

* Ca and Mn assumed present in equal molecular proportions.

weathering may have extended in the past depends on the level of ground water in past times. The conclusion arrived at is that the alteration of the rocks of the kodurite series with formation of oxidized ores may be guessed as having extended to a maximum depth of 500 feet.

[CHAPTER XVI.]

The Manganiferous Rocks of the Dhárwár Facies, including the Gondite Series.

Towards the end of the Archæan era there seems to have been a time during which a vast succession of sediments—clays, sandstones, limestones, etc.,—was deposited, accompanied by the extrusion of basic lava flows. These rocks have been since subjected to metamorphism as the result of tectonic movements, with the production of slates, phyllites, mica-schists, quartzites, crystalline limestones, complex gneisses, and hornblende-schists, the degree of metamorphism being different in different areas. At different times the following names have been proposed for the rocks of the different areas :—

Name of series.	Year.	Locality.
Chámpáner	1869	Gujarát.
Arávalli	1877	Rájputána.
Chilpi Ghát	1885	Central Provinces.
Dhárwár	1886	Dhárwár, Bellary, and Mysore.

Since it is almost certain that these different series are roughly contemporaneous it is desirable to use one name for the whole of them. For this purpose Dhárwár is chosen because it is the best known; and it is to be noted that the Dhárwárs of India are probably equivalent to the Huronians of America. Where the Dhárwárs have been subjected to more severe metamorphism than usual they have been rendered so crystalline that they can be separated from the remainder of the crystalline complex with difficulty only, and in the Nágpur-Bálághát portion of the Central Provinces are referred to as a portion of the *metamorphic and crystalline complex.*

It is supposed that during the deposition of the Dhárwár sediments manganese oxides were sometimes deposited chemically from solution.

In places where the degree of metamorphism to which these rocks were subsequently subjected was not great, any layers of manganese oxides were consolidated into manganese-ores, mechanically mixed with any impurities that may have been mechanically deposited with the manganese oxides. A good example of this is the Bálághát manganese-ore deposit.

But in places where these sediments with their manganiferous layers were subjected to considerably more intense metamorphism, through being folded in to a greater depth, a chemical reaction often took place between the manganese oxides and the clay or sand mixed with them. The result of such interaction was the formation of manganiferous silicates, especially the manganese-garnet, spessartite, and to a less extent the manganese-pyroxene, rhodonite. The series of rocks thus formed has been designated the *gondite series* after the race of so-called aborigines in the Central Provinces, known as the Gonds. The rocs of this series are of course only one particular facies of the Dhárwár series. They are found principally in the Bálághát, Bhandára, Chhindwára, and Nágpur districts, in the Central Provinces; at Kájli-dongri in Jhábua State, Central India; and at Jothvád in Nárukot State, Bombay.

By the subsequent oxy-alteration of these manganese-silicate-rocks manganese-ores have been formed. As they are supposed to have been formed in depth, they are referred to as *deep secondary ores*, to distinguish them from the *outcrop secondary ores*, often formed by the replacement of Dhárwár rocks at the surface.

The rocks and ores of the gondite series are found associated with a 'country' of phyllites, schists, quartzites, and gneisses. Manganese-ores are also found in *crystalline limestones* in association with the manganiferous epidote, *piedmontite*. Now the determination of the origin of these ores obviously depends upon determining that of the crystalline limestones. I have elsewhere put forward an opinion that some of the crystalline limestones of the Chhindwára district have been formed by the chemical alteration of quartz-pyroxenes-gneisses under the influence of waters containing carbon dioxide. Briefly the idea is as follows :—

Amongst the sediments deposited in Dhárwár times, there must

have been some calcareous ones, deposited chemically. Sometimes these were pure and sometimes they were rendered impure by admixture, at the time of deposition, with mechanical sediments, such as sand and clay. When this series of sediments was metamorphosed the pure calcareous sediments were converted direct into crystalline limestones, whilst the impure ones, owing to interactions between the calcareous matter and the sand and clay, were converted into gneisses with the liberation of carbon dioxide. These gneisses are the ones I have called quartz-pyroxene-gneisses. On the amelioration of the conditions of pressure and temperature under which these gneisses were formed, the carbon dioxide set free during their formation was able to attack the gneisses and bring about their more or less complete conversion into crystalline limestones, studded with accessory minerals, representing the constituents of the gneisses that were able to escape or resist this attack by carbon dioxide. In places amongst the original calcareous sediments, manganese oxides were chemically deposited, sometimes pure and at other times admixed with calcareous and other impurities. When these sediments were metamorphosed they were, if sufficiently pure, converted direct into crystalline limestones containing manganese-ore or piedmontite, according to whether the manganese oxides were deposited pure or admixed with calcareous matter. But where the whole mass of the sediment was impure, owing to admixture with sand, clay, etc., the resultant rock seems to have been a *piedmontite-gneiss*. This has been subsequently attacked with formation of piedmontite-limestone in the same way as the quartz-pyroxene-gneiss has been converted into limestone without piedmontite. It should be noticed that for the sediments to yield a gneiss on metamorphism they must have contained some felspathic material. It is doubtful if any considerable proportion of the manganese-ores in crystalline limestones has been formed by the subsequent chemical alteration of the manganese silicate, piedmontite; it seems more probable that in the majority of cases the manganese-ore was formed direct, by the compression of the manganese-oxide sediment originally deposited. Where, however, the limestones contain spessartite and rhodonite, as well as piedmontite, some ores seem to have been formed by secondary alteration; but such ores do not seem to be of any commercial importance.

At the end of this chapter the following classification is given of the manganese-ores associated with the Dhárwár rocks :—

Classification, according to origin, of the manganese-ores associated with the Dhárwár rocks.

A. With the less metamorphosed type of Dhárwárs :—	
(*a*).—*Primary ores* :—	
Balághát*	Psilomelane and pyrolusite ; rarely braunite and hollandite.
Panch Mahals*	
Singhbhum*(?)	
(*b*).—*Outcrop secondary ores* (*lateritoid ores*):—	
Dhárwár	Psilomelane, pyrolusite, wad, pseudo-manganite, and polianite(?).
Jabalpur*	
Mysore*	
North Kanara	
Panch Mahals	
Sandur Hills*	
Singhbum*	
B. With the more metamorphosed type of Dhárwárs :—	
(*a*).—*Primary ores* :—	
a. Associated with the gondite series.	
Probably some in nearly all the areas mentioned in *c.a.**	Same as *c.a.*
β. Associated with crystalline limestones.	
Nágpur district*	Hollandite, braunite, psilomelane.
(*b*).—*Outcrop secondary ores* :—	
a. Associated with the gondite series.	
Probably some in nearly all the areas mentioned in *c.a.*	Soft, dirty ores ; psilomelane and pyrolusite.
β. In cavities in crystalline limestone.	
Nágpur district	Pyrolusite.
(*c*).—*Deep secondary ores* :—	
a. Associated with spessartite- and rhodonite-bearing rocks (the gondite series).	
Nárukot	Psilomelane, braunite ; rarely hollandite, sitaparite, vredenburgite.
Jhábua*	
Fálághát*	
Bhandára*	
Chhindwára*	
Nágpur*	
β. Associated with crystalline limestones containing piedmontite, often spessartite, and rarely rhodonite.	
Chhindwára*	Psilomelane, braunite, and hollandite.
Názpur	
C. In laterite resting on the Dhárwárs :—	
Belgaum*	Psilomelane, pyrolusite, pseudo-manganite, and wad.
Goa*	
Jabalpur	

* Occurrences being worked in 1907.

[CHAPTER XV.]

The Gondite Series.

In this chapter the geology and origin of the portion of the Dhárwár series known as the *gondite series* is discussed in some detail.

The main conclusions as to origin are:—

1. That portions of the metamorphic and crystalline complex with which the manganese-bearing rocks of the gondite series are associated in the districts of Chhindwára, Nágpur, Bhandára, and Bálághát, are the more highly metamorphosed equivalents of the rocks that have been designated the Chilpi Ghát series in the Bálághát district.
2. That the manganese-bearing rocks are not intrusive in these metamorphosed sediments, but have been formed by the metamorphism of manganese-bearing sediments deposited contemporaneously with the sands, clays, and impure grits, from which these quartzites, mica-schists, and gneisses were formed.

One of the most important reasons for the second conclusion is the evidence that the mica-schists, spessartite-bearing rocks, and gneisses, of Ukua in the Bálághát district, are stratigraphically equivalent to the phyllites, interbanded manganese-ores and quartzites, and conglomeratic grits, respectively, of the Bálághát deposit.

[CHAPTER XVI.]

The Gondite Series—*continued.*

In this chapter are given lists of the minerals found in and associated with the rocks of the gondite series. This is followed by a brief account of the petrology of the series, with lists of the numerous rocks. A few of these are described. The most important is *gondite*. This is a rock composed of a mixture of quartz and spessartite-garnet in varying proportions. It is typically fine-grained, so that it sometimes looks at first sight like a quartzite. But it may be very coarse-grained, when the spessartite often occurs as well-formed crystals of considerable beauty.

[CHAPTER XVII.]

The Gondite Series—*concluded.*

In a discussion of the chemical composition of the series it is shown that gondite and rhodonite-quartz-rock would have the compositions shown below, according as the constituent minerals were present in equal proportions by weight or by volume :—

	Gondite. (Spessartite-quartz-rock.)		Rhodonite-quartz-rock.	
	Equal parts by weight.	Equal parts by volume.	Equal parts by weight.	Equal parts by volume.
MnO	21·46	26·25	27·02	31·25
Al_2O_3	10·29	12·57	..	..
SiO_2	68·25	61·18	72·98	68·75

An actual analysis of a piece of typical gondite from the Chhindwára district corresponds to the following mineral composition :—

	By weight.	By volume.
Spessartite	57·94	46·30
Quartz	42·06	53·70

The spessartite is not, however, of the theoretical composition corresponding to the formula $3MnO.Al_2O_3.3SiO_2$, but has a part of the MnO replaced by FeO, CaO, and MgO.

The question of the alteration of the rocks of the gondite series with formation of manganese-ores is then discussed ; the conclusions arrived at as to the origin of the gondite series and the associated manganese-ores may be summed up as follows :

Points that may be considered as fairly certain :—

1. The rocks of the gondite series are the product of the metamorphism of the less pure manganiferous sediments of Dhárwár age, the metamorphism of these sediments having taken place towards the end of the Dhárwár period.

2. A portion of the ores has been formed directly by the compression of the purest of the original manganese-oxide sediments.
3. Another portion of the ores has been formed by the subsequent alteration of the manganese silicates produced by the above-mentioned metamorphism.

Points that are more doubtful :—

4. The ores formed by the alteration of the rocks of the gondite series were formed by a combined decomposition and replacement of the gondite, spessartite-rock, or rhodonite-rock, as the case may be.
5. The alteration of manganese-silicates to manganese-ores took place at the close of the Dhárwár period of folding, and hence in Archæan times.
6. The alteration took place at considerable depths, so that, taken in conjunction with the supposition that a portion of the ores are merely compressed manganese-oxide sediments, workable ores may be expected to extend in some places to as great a depth as the rocks of the gondite series.
7. The alteration was due to the attack on the manganese-silicate-rocks by waters containing either carbon dioxide or sulphuric acid, more probably the former; and also oxygen.
8. The carbon dioxide may have been a portion of that liberated in the conversion of original impure calcareous sediments into the quartz-pyroxene-gneisses of this area; and the oxygen a portion of that liberated in the conversion of original impure manganiferous sediments into the manganese-silicate-rocks.
9. A small proportion of softish and more or less porous ore has been formed since the rocks of the gondite series were exposed at the surface, and is probably still being formed.

[CHAPTER XIX.]

Manganese in Laterite.

Laterite consists essentially of a mixture of hydrated oxides of iron and alumina, with often a considerable percentage of titania, and

sometimes a large percentage of manganese oxide, although laterite is often quite free from this constituent. When iron oxides predominate the rock may be of value as an ore of iron; when it consists chiefly of oxide of aluminium it is known as bauxite and is of use as an ore of aluminium; whilst when manganese oxides predominate, usually in the form of psilomelane, pyrolusite, or wad, the rock is an ore of manganese.

Laterites can be divided into two main divisions according to their situation, namely *low-level laterite* and *high-level laterite*. The only authenticated occurrence of manganese in low-level laterite is in Goa.

The *high-level laterite* is found in its best development on the Deccan plateau, and in the Central Provinces and Central India. It is usually confined between the elevations of 2,000 and 7,000 feet. Numerous theories have been advanced to account for the origin of high-level laterite; of these the following are the most important:—

1. H. B. Medlicott and W. T. Blanford consider two possible methods of formation: namely that the rock has been formed as the result of the alteration *in situ* of various rocks, especially of basalt, and that it may be a sedimentary rock. They give objections to both hypotheses.
2. F. R. Mallet supposes that the laterite may have been formed in lakes occupying shallow depressions on the surface of the Deccan Trap, at the close of its period of eruption, by being precipitated as oxides of iron from waters draining into the lakes, partly by the action of oxidizing influences, and partly as the result of the vital activity of organisms, such as algæ, living in the lakes.
3. T. H. Holland suggests that the rock is formed *in situ*, as the result of the chemical alteration of rocks, the energy necessary for the breaking up of the silicates being derived from the vital activity of organisms.
4. E. W. Wetherell supposes that the laterite of the Bangalore and Kolar districts in Mysore is of detrital origin and was formed by the washing of the decomposed surface detritus of the surrounding elevated ground into a lake, where it became mixed with non-detrital material to a small extent,

and was subsequently cemented by the action of segregative tendencies, due to the presence of some organism in the lake, such as one allied to *Girvanella*. This theory is only a variant of Mallet's.

5. J. M. Maclaren, relying on a very clear section at Talevádi in the Belgaum district, holds that lateritic deposits are derived from mineralized solutions brought to the surface by capillarity, and are essentially replacements—mechanical or metasomatic—of soil, or of rock decomposed *in situ*, or of both.

An actual case is then considered, namely the bauxitic laterite of the Yeruli plateau in the Sátára district. The conclusion arrived at is that the uppermost portion of this laterite has been formed in the way supposed by Mallet, and that the underlying portions have been formed by the chemical alteration of the trap rocks *in situ*. And the point is emphasized that no one theory of origin can be applied to all laterites, but that each case must be considered on its merits.

In the formation of laterite manganese often seems to have been entirely removed. When present it does not seem to form intimate mixtures with the oxides of iron and alumina in the same way as these two do with one another; on the other hand it nearly always appears as definite segregations in the ordinary laterite, although there are exceptions to this. Of all the many occurrences of manganese-ore in lateritic rocks, however, only three are in rocks that would be called laterite without hesitation. These are the occurrences of Goa, Talevádi in Belgaum, and Gosalpur in the Jabalpur district.

The remainder of the occurrences of manganese-ore are in a rock that some geologists would probably designate laterite; but others would probably object to the application of this term. The rock referred to has a lateritic aspect and usually consists of a cavernous mixture of various oxides of iron, chiefly hard limonite, yellow ochre, and soft hematite. When no other constituents are present, the rock often resembles typical laterite so closely in its structures and mineral composition that when detached from its rock masses it could not be distinguished from pieces of ordinary ferruginous laterite (of non-detrital origin). It frequently contains ores of manganese—wad,

psilomelane, or pyrolusite—irregularly mixed with iron-ores. But this rock does not always consist entirely of iron and manganese-ores. It often contains patches of quartz, quartzite, slate, or phyllite. Under the microscope it is seen that these are residual pieces of rock set in a matrix of ore, and that the latter has been formed by the metasomatic replacement of the former. Examination of the masses of rock in the field, especially as revealed in the workings for manganese, confirms this deduction, and shows that there is a downward passage from the lateritic mass of iron and manganese-ore at the surface, through rock containing more and more quartzite, slate, or other rock, and less and less ore, to a rock free from all signs of ore. As the rocks that have undergone this conversion into ores by metasomatic replacement do not usually contain more than a very small proportion of manganese, it is evident that the manganese must have been brought in from outside by percolating waters. On account of the limited extent of each of these masses of rock, their different elevations, their want of horizontal bases, and the numerous cases in which the rock contains angular fragments of other rocks, most geologists would probably prefer to consider these occurrences as distinct from the masses of typical laterite occurring in horizontal sheets, often of considerable extension, and free from included fragments of rock different in character from the laterite. For this reason these occurrences are referred to in this Memoir as *lateritoid*, to indicate their similarity to laterite, and yet introduce a distinction. It is evident that my views as to the origin of these masses of lateritoid and their included manganese-ores are practically identical with Maclaren's theory of the origin of laterite in general. The high-level laterite of Talevádi on which Maclaren bases his theory undoubtedly is related to the lateritoid occurrences, and may be considered as the connecting link between lateritoid and true high-level laterite.

The term *lateritic* is taken to include both true laterite, high-level and low-level, and lateritoid, and the following classification is given of the lateritic manganese-ores :—

Classification of the deposits of lateritic manganese-ores.

I.—In low-level laterite :—

1. Goa.
2. Chengalput.

II.—In high-level laterite :—

(*a*) On the Deccan Trap :—

1. Bidar.
2. Bijapur (Ingleswára)

(*b*) On the Dhárwárs :—

1. Talevádi in Belgaum.

III.—In lateritoid (always on the Dhárwárs) :—

1. Bengal :—Singhbhum.
2. Bombay :—Dhárwár, North Kanara.
3. Central Provinces :—Jabalpur.
4. Goa.
5. Madras :—Bellary, Sandur.
6. Mysore :—Chitaldrug, Kadur, Shimoga, Tumkur.

IV.—In lateritic soil resting on the Deccan Trap :—

1. Sátára.

V.—Exact mode of occurrence unknown :—

1. Morbhanj.

Although as a rule the lateritic deposits are not of great economic importance, yet the deposits of one area—the Sandur Hills—compare favourably, as regards total quantity of ore available near the surface, with those of almost any other area in India of similar size.

[CHAPTER XX.]

Manganese in the Tertiary and Recent Formations.

Several interesting occurrences of manganese-ore of recent age are noticed, and then the origin of deep-sea manganese nodules is discussed.

From a consideration of the figures put forward by Murray it is concluded that had all the manganese that is being constantly brought into the oceans by the rivers remained in solution, every cubic mile of sea-water would now contain 1,140,600 tons of manganese sesquioxide, so that the manganese would form 0·7% of the total salts dissolved in sea-water. Since analyses of the total salts omit any reference to manganese, it is concluded that most of the manganese must have been removed from solution in the waters of the ocean. Reasoning from this point of view, and also considering the hypotheses

previously put forward, the following ideas as to the origin of the deep-sea manganese nodules are formed :—

1. The manganese, although probably partly derived from cosmic dust and volcanic débris, has been mostly precipitated from solution in sea-water, the manganese salts having been originally brought into the sea by rivers.
2. The manganese oxide, although possibly partly precipitated as a result of the vital processes of organisms, both vegetable and animal, has been mainly precipitated by calcium carbonate aided by the process of segregation from solution round a nucleus.
3. Where the sea bottom consists largely of calcareous sediments, the precipitation may have been brought about mainly by the solution of some of this calcium carbonate, with the deposition of an equivalent amount of manganese oxide, owing to the presence of free oxygen.
4. Where the sea-bottom consists of red clay, it does so because the depths are there so great that the tests of thin-shelled organisms are completely dissolved by the sea-water before they reach the bottom. The calcareous matter in being dissolved deposits an equivalent amount of manganese oxide, which descends to the bottom, and there acts as a nucleus for the segregative extraction of manganese from the waters at the sea-bottom. The deposition of manganese oxide by means of calcium carbonate associated with the red clays probably also occurs to a subordinate extent, for the shells of thick-shelled organisms may reach the bottom before being entirely dissolved.

[PART III.]

[ECONOMICS AND MINING.]

[CHAPTER XXI.]

History of the Indian Manganese Industry.

From time immemorial manganese-ores have been worked to a small extent by the natives of India, the uses to which they put the ores being in glass-making, as *surma* for the eye-brows, and in the manufacture of special brands of iron. And in connection with this it is interesting to note that there is at least one word that apparently signifies manganese-ore as distinct from other ores. This is *waral*, used by the Dhávads of Mahábaleshwar.

It was not until 1892, however, that any attempt was made to work the Indian deposits for export to the European and American markets. During the following years the manganese-quarrying industry has spread to many parts of India, and the export of this commodity has now reached such a large figure that in 1906 India reached the first place as a producer of manganese-ore, which position she probably retained during 1907.

The following table shows the dates at which the industry started in the various parts of India :—

District or State.	Province.	Year
Vizagapatam	Madras	1892
Nágpur	Central Provinces	1899
Bálághát	Ditto	1901
Bhandára	Ditto	1901
Jhábua	Central India	1903
Singhbhum	Bengal	1904
Belgaum	Bombay	1905
Sandur	Madras	1905
Shimoga	Mysore	1905
Panch Mahals	Bombay	1906
Chhindwára	Central Provinces	1906
Goa	Portuguese India	1906
Chitaldrug	Mysore	1906
Tumkur	Ditto	1906
Las Bela	Baluchistán	1907
Jabalpur	Central Provinces	1907

An account of the fluctuations in the price of manganese-ore is also given.

[CHAPTER XXII.]

Statistics of Production of Manganese-ore in India.

Detailed figures of production (as far as possible of ore raised and not ore railed) are given deposit by deposit, based largely on information obtained direct from the mine operators. It is only by obtaining the figures of output given separately for each deposit in this way that one can hope to be able to check the accuracy of the information supplied. Hence it is hoped that these figures will be taken as superseding those previously issued in the reports of the Chief Inspector of Mines in India, and in the Annual Reviews of Mineral Production in India. The annual output figures are summarized in the following table :—

Year.	Baluchistan.	Bengal.	Bombay.	Central India.	Central Provinces.	Madras.	Mysore.	Totals.
	Long tons.	Long tons.	Long tons.	Long tons.	Long tons.	Long tons.	Long tons.	Long tons.
1892	..	..	..	..	..	674	..	674
1893	..	..	..	..	..	3,130	..	3,130
1894	..	..	..	..	..	11,410	..	11,410
1895	..	..	..	..	..	15,816	..	15,816
1896	..	..	..	..	..	56,869	..	56,869
1897	..	..	..	..	..	74,467	..	74,467
1898	..	..	..	..	..	62,980	..	62,980
1899	..	..	..	..	..	84,652	..	84,652
1900	..	..	..	..	47,257	92,008	..	139,265
1901	..	..	..	..	81,263	76,473	..	157,736
1902	..	..	..	..	76,154	68,171	..	144,325
1903	..	..	..	6,800	107,947	63,074	..	177,821
1904	..	..	..	11,564	85,024	53,602	..	150,190
1905	..	..	640	30,251	151,547	64,989	..	247,427
1906	..	1,000	7,520	50,073	351,880	114,710	46,312	571,495
1907	15	2,933	22,617	35,743	540,577	159,219	112,807	873,911
Totals.	15	3,933	30,777	134,431	1,441,649	1,002,244	159,119	2,772,168

Note :—In 1907 some 7,000 to 8,000 tons of manganese-ore were mined in Goa.

Nine of the Indian deposits have yielded over 100,000 tons of manganese-ore up till the end of 1907. They are as follows :—

	Total output in long tons.
Garbhám	553,140
Kodur mines	276,364
Bálághát	210,601
Kándri	175,726
Mansar	154,358
Lohdongri	147,787
Kájlidongri	134,431
Kumsi	113,667
Chikhla I	100,477

After comparing the Indian output figures with the variations in price, tables are given showing the output of manganese-ore and manganiferous iron-ore by the various countries of the world since 1890. Tables showing the yearly exports of Indian manganese-ore and the distribution of it when exported are also given.

[CHAPTER XXIII.]

Labour and Costs of Production.

The daily number of workers employed in the Indian manganese quarries has risen from about 1,000 in 1895 to about 14,000 in 1906, and probably about 20,000 in 1907.

The various items in the cost of putting Indian manganese-ore on the markets in Europe and America are considered, and the following figures are deduced as representing the average cost per ton of delivering ore from the various producing provinces *c. i. f.* at English and Continental ports :—

Average Cost of Indian Manganese-ore delivered c. i. f. at English and Continental Ports.

Area from which derived.	Port from which exported.	Average cost per ton.	
		Rs.	*a.*
Central Provinces	Bombay . .	26	14
Ditto	Calcutta . .	31	6
Jhábua, Central India	Bombay . .	22	1
Vizagapatam, Madras	Vizagapatam .	23	7
Sandur, Madras	Mormugao .	23	7
Mysore	Mormugao .	29	8

[CHAPTER XXIV.]

Valuation and Chemical Composition of Manganese-ores.

Ores of manganese and iron are usually classified for commercial purposes into three groups :—manganese-ores, manganiferous iron-ores, and iron-ores. The second term is considered to be too loosely applied ; it is used to include ores containing a much larger percentage of manganese than of iron. *i e.*, for ores that would be more accurately designated *ferruginous manganese-ores.* For classifying ores containing an amount of Mn + Fe equal to 50% or over the following figures are put forward :—

	Mn per cent.	Fe per cent.
Manganese-ores	40—63	0—10
Ferruginous manganese-ores	25—50	10—30
Manganiferous iron-ores	5—30	30—65
Iron-ores	0—5	45—70

Analytical figures are then given of samples and hand-specimens of Indian ores from the various districts and States, and also of the cargoes as received at Middlesborough ; and for comparison a table is given of analyses of manganese-ores from all parts of the world.

Reference is also made to the following of the rarer constituents of Indian manganese-ores :—Al, Ba, Ca, Mg, K, Na, As, S, Co, Ni, Cu, Pb, Zn, Ti, combined water, and CO_2.

[CHAPTER XXV.]

Value of the Indian Manganese-ore Production.

By making use of the figures of cost of production given in the previous chapter and the current market values of the Indian ore according to its analysis, detailed figures of the *f. o. b.* or export value

of the ore produced in each area are worked out. They are summarized in the following table:—

Export Values in Sterling, f. o. b. at Indian Ports, of the Manganese-ore produced in the various Provinces of India from 1892 *to* 1907.

Year.	Baluchistan.	Bengal.	Bombay.	Central India.	Central Provinces.	Madras.	Mysore.	Totals.
	£	£	£	£	£	£	£	£
1892	..	..	..	..	..	1,050	..	1,050
1893	..	..	..	..	..	4,460	..	4,460
1894	..	..	..	..	..	11,220	..	11,220
1895	..	..	..	..	..	14,037	..	14,037
1896	..	..	..	..	..	66,821	..	66,821
1897	..	..	..	..	..	80,362	..	80,362
1898	..	..	..	..	..	55,895	..	55,895
1899	..	..	..	..	..	91,354	..	91,354
1900	..	..	..	..	100,618	125,744	..	226,362
1901	..	..	..	..	133,407	82,527	..	215,934
1902	..	..	..	..	93,923	57,093	..	151,016
1903	..	..	..	5,638	138,982	43,889	..	188,509
1904	..	..	..	9,588	91,047	37,298	..	137,933
1905	..	..	19	19,159	162,281	41,972	..	223,431
1906	..	1,417	13,904	70,938	700,828	114,212	67,779	969,078
1907	20	5,010	46,880	61,061	1,193,774	238,300	203,420	1,748,465
Totals.	20	6,427	60,803	166,384	2,614,860	1,066,234	271,199	4,185,927

In comparing the value of the manganese-ore with that of other minerals produced in India it is usual to use the export value of the manganese-ore. According to this method manganese-ore was the sixth in order of value for the years 1903 to 1905, and third in 1906 and 1907

But the true value on the world's markets is the *c. i. f.* value of the ore. Inserting this in the table of values and making a few corresponding alterations in the figures for other Indian minerals, manganese-ore is seen to stand fourth in order of value in 1906 and third in 1907. Most of the other Indian mineral products are not, however, valued in the raw condition, but in the condition in which they are fit for man's use. If the manganese-ore be given the value the manganese has when converted into ferro-manganese, then manganese-ore shares the first place with coal as regards value. Since, however, the value to India is the export value of the ore, and not either its *c. i. f.*, or ferro-manganese value, it is evident that the difference between the export value and the ferro-manganese value may be taken as a rough measure of the loss that India suffers by exporting its ore in the raw condition, instead of smelting it in the country. The following table shows the value o the Indian output of manganese-ore for the years 1905, 1906 and

1907, according to the three different methods of evaluating, and also the total value from the beginning of the industry to 1907 :—

Year.	Export or *f. o. b.* value.	*c. i. f.* value.	Ferro-manganese value.
	£	£	£
1905	223,431	454,364	2,096,952
1906	969,079	1,502,471	4,971,998
1907	1,748,465	2,564,115	5,024,982
1892—1907 . . .	4,185,927	6,773,283	17,422,692

[CHAPTERS XXVI AND XXVII.]

The Mining and Quarrying of Manganese-ores.

In the former of these chapters the way in which it would be best to work the Indian manganese-ore deposits, taking into consideration their geological structure, is considered. In the second chapter a description is given of the methods actually in use in the Indian manganese quarries, and attention is drawn to the waste of valuable ore that takes place in some quarries with the present methods of work. And to show that in some countries it is thought worth while to employ more elaborate methods in mining the ores, to win lower grade ores than are considered worth notice in India, and, if necessary, to subject the ore when won to some sort of mechanical concentration, a short account is given of methods in vogue in Brazil, Virginia, Panama, and other countries.

[CHAPTER XXVIII.]

The Uses of Manganese.

An attempt is made in this chapter to bring together such facts as are available concerning the manufacture of spiegel-eisen and ferro-manganese, the literature of which is very scanty and scattered. It is

shown that the difference between the cost of the materials that would be required to manufacture ferro-manganese in India, and the price the alloy produced would fetch on the European and American markets is so large that it is improbable that the other items in the manufacture of this alloy besides the cost of materials—and concerning which no figures are available—would account for the whole of this difference; and in fact that it is not improbable that considerable profit would attach to the manufacture of ferro-manganese in India, once a market for it had been obtained.

Accounts are also given of the use of manganese-ore in India in native iron-smelting, in colouring glass and enamels, and for pottery, and of the use and valuation of peroxide ores as a source of oxygen.

MEMOIRS

OF

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VOLUME XXXVII.

THE MANGANESE-ORE DEPOSITS OF INDIA, *by* L. LEIGH FERMOR, A.R.S.M., B.Sc. (London), F.G.S., *Assistant Superintendent, Geological Survey of India.*

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THE

MANGANESE-ORE DEPOSITS OF INDIA

PART I

INTRODUCTION AND MINERALOGY

ABRIDGED CONTENTS OF PART I.

CHAPTER.		PAGE.
I.	*Introduction*	3
II.	*Mineralogy*—General	21
III.	Oxides	37
IV.	Manganates and Carbonates	87
V.	Silicates—Pyroxenes and Amphiboles	125
VI.	Silicates—Garnets	161
VII.	Silicates—Epidotes, Micas, etc.	187
VIII.	Titano-silicates, Niobates, Phosphates, and Tungstates	201
IX.	Associated Non-manganiferous Minerals	211
X.	Identification of Manganiferous Minerals	223

THE

MANGANESE-ORE DEPOSITS OF INDIA

PART I

INTRODUCTION AND MINERALOGY

CHAPTER I.

INTRODUCTION.

History of the investigation—Scope of this Memoir—Acknowledgments—Analytical work—The visitor to India—Literature of Indian manganese-ore deposits—Literature of foreign manganese-ore deposits.

Nature of manganese—Origin of the word 'manganese'—Recognition as a new element—Distribution in Nature—In the mineral kingdom—In the vegetable kingdom—In the animal kingdom.

History of the investigation.

Although it has long been known that ores of manganese exist in various widely separated parts of India, yet it was not until 1891 that any serious attempt was made to work them. In that year a syndicate, which later was formed into the Vizianagram Mining Company, Limited, started work on the deposits of the Vizagapatam district, Madras, the first export of ore taking place in 1892; since then prospecting over various parts of India has led to the discovery of many other deposits, and to the opening up both of the newly discovered deposits and of those that were previously known and had been noticed in Ball's Economic Geology. The production of manganese-ore in India has increased almost continuously from year to year, so that this country has taken a higher and higher place amongst the manganese-producing countries of the world. In 1906, India probably reached the first place, which she is likely to retain for at least the present year. Before the beginning of the

industry the Geological Survey was in possession of nearly all the information—summarized in Ball's Economic Geology and Mallet's Mineralogy—that was available concerning the Indian manganese-ore deposits. But, as so often happens when a particular set of mineral deposits is first opened up, our knowledge of the deposits did not increase commensurately with the development of the industry; and the geological evidence made available by the opening up of the manganese quarries was neglected. Consequently by the year 1903 there was a flourishing industry in our midst about which the Geological Survey knew very little; and in this same year I was deputed by Dr. Holland, Director of the Geological Survey, to investigate the manganese-ore deposits of India.

During the previous field season (1902-03) I had, in company with Mr. E. Vredenburg, first come into contact with manganese-ore deposits in the field; namely, in Indore State and the Dhár Forest in Central India, and in the Hoshangábád and Nimár districts in the Central Provinces. During the ensuing field seasons I visited the following manganese areas:—

1903-04.—Nágpur, Chhindwára, Bhandára, Bálághát and Jabalpur districts, Central Provinces.

1904-05.—Jabalpur district, Central Provinces; Ganjám and Vizagapatam districts, Madras; Singhbhum district, Bengal; Jhábua State, Central India; Panch Maháls and Sátára districts and Nárukot State, Bombay.

In December, 1906, I was able to revisit the deposits of Kándri, Mansar, Sátak, Beldongri, Lohdongri, Kácharwáhi, Waregáon, Mándri, and Mánegáon, in the Nágpur district, and bring my knowledge with regard to these deposits up to date. I was also able to examine two fresh deposits; Panchála in Nágpur and Asalpáni II (Karli) in Bhandára.

During August and September, 1907, I made a brief examination of a few of the deposits in the Sandur State, Bellary district, Madras; and during September, in the Chitaldrug, Kadur, Shimoga, and Tumkur districts, Mysore. In October and November, 1907, I found a few occurrences of manganese-ore in the Nilgiri Hills, and in the latter month paid a short visit to some of the deposits in the Portuguese territory of Goa. In December, 1907, I visited Talevádi in Belgaum, and revisited parts of the Central Provinces; whilst in January, 1908, I was able to examine Leda Hill in Singhbhum.

Of the manganese areas not examined by me, Mr. J. M. Maclaren visited the Belgaum and Dhárwár districts (in 1905); and he has kindly supplied me with notes and specimens from the deposits of these parts. During the field season of 1906-07 Messrs. H. Walker and A. M. Heron, whilst working in the Jhábua State, were able to examine some unimportant deposits not visited by me; I have made use of their notes in amplifying the account of the deposits of Jhábua.

It will thus be seen that some considerable time has elapsed since the main body of the field work was carried out. Before the investigation was begun, the little knowledge we had about this mineral did not lead us to expect results of more than ordinary interest. The field-work, however, showed that the manganese-ore deposits are in some parts, notably the Central Provinces, Vizagapatam, Jhábua, and Nárukot, associated with most interesting and fascinating series of rocks; and that the deposits themselves contain many rare minerals and not a few species and varieties new to science. It was felt that even bare justice could not be done to the subject without a somewhat detailed investigation of these rocks and minerals.

Further, during the laboratory examination of these specimens, fresh specimens, and information relative to the discovery of new deposits of manganese-ore, have been pouring in from miners and prospectors in all parts of India. Hence the delay in the appearance of this account of the Indian manganese-ore deposits. The gap has been to a certain extent filled by the publication of the paper entitled 'Manganese in India', referred to on page 11. It was read on March 26th, 1906, and published in the autumn of the same year.

Scope of this Memoir.

I have endeavoured to treat the subject of this Memoir with some fullness, from each of the following points of view:—Mineralogical (Part I), geological and genetic (Part II), economic (Part III), and descriptive (Part IV). I have not, however, been able to keep in touch with all the fresh discoveries, and can usually give only meagre accounts of deposits not visited by myself or one of my colleagues. Even whilst this work is passing through the press fresh discoveries are being made, accounts of which it will be impossible to include. But although I have not been able to examine every known deposit, I do not think I have missed any important type. In the descriptive part of this Memoir I have given fairly detailed accounts of a large number of deposits. It might be thought that a

general account of the deposits of each type would have been sufficient. Almost every deposit, however, has its own peculiarities and interesting features, structural, mineralogical, or petrological; whilst such details of the structure of each deposit as can be given will be very useful to the mining community, in helping to the rational development of the deposits. In the mineralogical section I have described several new species and varieties of minerals, in sufficient detail to warrant the bestowal of new names; most of these descriptions are, however, incomplete; but I hope that it may be possible in the future to investigate some of the many points that still require elucidation. There are several other minerals that are probably new, but which I have not been able to examine in any detail. Nevertheless for the sake of convenience and future reference, I have given an account of their characters as far as they have been determined; these points may require some modification when the minerals are examined in more detail. During the microscopic examination of thin sections of the rocks, I detected several other minerals that were not visible macroscopically, and could not be identified at the time. Whether they are new minerals, or previously known but rare minerals, has not been determined. They are not mentioned in this Memoir. As the fulness of the mineralogical treatment might render this work less useful to mining men, and prevent it from being of use to them in the identification of the minerals they find, I have inserted at the head of each of the more important minerals a short account of its chief features as given in Dana's System of Mineralogy, 6th Edition, and appendices.[1] Further, I have added a chapter on the identification of the Indian manganese minerals, which will, I hope, enable anyone with a little mineralogical knowledge to identify the minerals commonly found in the Indian manganese-ore deposits. The treatment of the economic side of the subject is not as full as I should have liked, particularly with regard to the details of costs of working and despatch to the smelting centres; but that the mining community should often be reticent on these points is not surprising, considering the keen competition that exists in the manganese industry.

Acknowledgments.

Such information as I possess relative to the economics of the subject has been obtained through the courtesy of the various members of the mining community, companies, syndicates, and individuals. Further, I must express here my indebtedness to the various companies and syndicates for the permission,

[1] It is this edition of this well-known work that I shall refer to as Dana's Mineralogy in the body of this Memoir.

always readily given, to visit their properties and publish freely any information obtained. I am also deeply grateful to the managers of these companies and syndicates, and to the managers of the various mines, for the courtesy with which they have in every way facilitated my visits to their properties; for the readiness with which they have answered questions, sometimes, perhaps, of too inquisitive a nature; and lastly for the kind way in which they have often personally shown me the main features of their deposits, so that I have been able to carry out a detailed examination with the salient points already grasped.

I cannot do better than quote here a remark of that eminent exponent of the science of ore-deposits, Professor Franz Pošepný. In his work entitled 'The Genesis of Ore-Deposits', p. 3, (1902), he says

'Mining, indeed, constantly furnishes fresh evidences in new openings, but it destroys the old at the same time; and if these are not preserved for science before it is too late, they are lost forever. The whole mining industry is in its nature transitory; but the nation, which intrusts to the miner, upon certain conditions, the extraction of its mineral wealth, has a right to demand that the knowledge thus gained at the cost of a part of the national resources shall not be lost to science.'

Now, although most members of the manganese-mining community of India may not have read this passage, yet they seem to be imbued with the spirit of it. They do not, as a rule, record these 'fresh evidences' themselves; but they are only too willing to draw the attention of the geologist to the discovery of what seems to them an interesting or important exposure or mineral, and further to facilitate in every way his personal visit to the place of interest and examination of the same. The fault of the non-recording of every interesting piece of geological interest exposed lies perhaps with the geologist, for he is often unable, from pre-occupation with other work, to accept an invitation to visit the point of interest. This fault is, however, not personal, but due to the fact that a comparatively small body of men have the guardianship, so to speak, of the mineral resources of an area that is almost as big as a continent and out of all proportion to their numbers.

If the members of the Indian manganese-mining community find this Memoir of interest or value to themselves, I shall be happy if they realize that it has only been rendered possible through their cordial co-operation and friendly interest.

The various companies, syndicates and individuals to whom I am indebted in the various ways specified above are the following:—

Bombay Company, Limited; Central India Mining Company, Limited; Central Provinces Prospecting Syndicate; Indian Manganese Company,

Limited; Jambon & Cie; Gordon, Woodroffe & Co.; Jessop & Co.; Kiddle, Reeve & Co.; P. Macfayden & Co.; Macqueen Bros.; Madhu Lall Doogar Mining Syndicate; New Mysore Manganese Co., Limited; Peninsular Minerals Company of Mysore, Limited; Shaw, Wallace & Co.; Shimoga Manganese Company, Limited.

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In addition, my thanks are due to certain of the officials of the districts and States I have had occasion to visit, for help given me whilst moving in their respective areas; and to certain of my colleagues, particularly Dr. Holland,[1] Messrs. Middlemiss and Vredenburg, and Dr. Christie, for their kindly suggestions and criticisms. I have also to thank Mr. H. B. W. Garrick, Artist to the Geological Survey, for several excellent photographs of mineral specimens, to which, however, justice has not been done in the reproduction. Further, two students—G. G. Narke of Nágpur and Kiran Sengupta of Calcutta—working in the laboratory of the Geological Survey of India, have given me considerable help in testing minerals, taking specific gravities, and compiling statistics.

Analytical work.

A work of this sort would have been impossible without a considerable number of analyses, both of ores and picked mineral specimens. For these I am largely dependent on a series of 84 partial and complete analyses carried out at the Imperial Institute by Mr. G. S. Blake, under the supervision of Professor W. R. Dunstan, and to a further series of 67 partial and complete analyses carried out by Messrs. J. and H. S. Pattinson of Newcastle-on-Tyne. These have been supplemented by several other analyses, particularly of picked specimens of minerals, carried out in the Geological Survey laboratory, chiefly by Mr. T. R. Blyth, Assistant Curator of the Geological Museum, but partly by my colleague, Mr. J.

[1] Now Sir Thomas H. Holland, K.C.I.E.

Coggin Brown, and by myself. Messrs. Winch and Fawcitt have also kindly analysed a few specimens of manganese minerals. Further I have been supplied with a considerable series of analyses by the various manganese mining companies, carried out partly by their own chemists, and partly by well-known firms of chemists in England: the chemists in India to whose analyses I have had access are Messrs. R. D. Connell, H. H. Dains, C. S. Fawcitt, S. A. Jones, G. M. Prichard, V. G. Speira, H. J. Winch, and Dr. Schulten; whilst the English firms are Messrs. J. and H. S. Pattinson of Newcastle-on-Tyne, Pattinson and Stead of Middlesborough, W. N. Pearson & Co. of London, and E. Riley of London. The fact that I have not taken any samples for analysis of the ores of Southern India—Sandur, Mysore, Goa, and Belgaum—may give rise to comment; the reason is that I was not able to visit these parts until this work was practically finished.

The visitor to India.

Should any mineralogist or geologist become sufficiently interested in the manganese-ore deposits of this country to pay it a visit, he will be well repaid for his trouble. If he wish to see the pick of the deposits, let him visit Kándri, Bálághát, Garbhám, Kájlidongri, and Kumsi; if he wish to feast his eyes upon apparently endless and unlimited supplies of ore, let him visit the Kamátaru section of the Sandur Hills; and if he would like an exciting time amongst the minerals and rocks, let him visit Kácharwáhi, Sitapár, Kájlidongri, Mansar, and Kodur, for from any one of these deposits he could collect in a day material sufficient to provide him with months of research work, whilst he would probably find minerals he had not seen before, and possibly varieties and species new to science. I am sure the managers of the various companies would gladly grant him permission to visit their properties, provided his objects were purely scientific. Should any one be unable to visit India and yet desire to work out any of the numerous points I have left untouched, and only a small proportion of which I can ever hope to deal with myself, I am sure the Director of the Geological Survey would gladly let me supply such material as I have.

Literature of Indian manganese-ore deposits.

In the course of this investigation I have, of course, collected and examined all the literature I could find on the subject of manganese in India. From the list of papers given at the end of this work it will be seen that the subject has apparently been extensively dealt with before. This is not the case; for most of these references are of trivial

importance, being mere records or short accounts of isolated occurrences. Some of them, however, are of more importance, and to these I shall here refer.

Leaving out a vague reference by Dr. W. Ainslie [1] in 1813 to the occurrence of manganese in Mysore, the earliest references to the occurrence of manganese in India are contained in two papers by Captain F. Jenkins[2] and Dr. H. W. Voysey[3], respectively, dealing with the mineralogy and geology of the Nágpur area, Central Provinces; the manganese-ore deposits referred to occur in crystalline limestone and are described in this Memoir as the Junawáni and Ghogara deposits. After this Lieutenant (and later Captain) T. J. Newbold, F.R.S., in a series of papers on the mineralogy and geology of Southern India published between the years 1840 and 1846, mentions several occurrences of manganese-ore in Madras, Bombay, Mysore, and Haidarábád. Of these the most important are the accounts of the occurrence in the Kappat Gudda at Chik-Vadvati [4] [the Chick Wodoorti of Newbold], and of the lateritic manganese-ore of Bidar in Haidarábád [5]. In 1852 Dr. A. J. Scott[6] published an account with analyses of two specimens of manganese-ore from the Vizagapatam district, he being the first to discover the existence of braunite in India. In 1879, F. R. Mallet published two papers entitled 'On Braunite, with Rhodonite, from near Nágpur, Central Provinces'[7], and 'On Pyrolusite with Psilomelane occurring at Gosalpur, Jabalpur District' [8]. On pages 326-332 of Part III, Economic Geology, of the Manual of the Geology of India, published in 1881, V. Ball gave a very good summary of all that had been written previous to this date on the subject of Indian manganese-ores. To this work I shall refer in the body of this Memoir as Ball's Economic Geology. A further paper by F. R. Mallet, entitled 'On Lateritic and other Manganese Ore occurring at Gosalpur, Jabalpur district'[9], was published in 1883; whilst the same author on pages 55-59, 61, 62, 84, 90, 113, 139, 140, of Part IV, Mineralogy, of the

1 'Materia Medica of Hindoostan', p. 57.

2 *Asiatic Researches*, XVIII, pt. 1, pp. 208, 210, (1833); abstract in *Glean. Sci.*, I. pp. 226, 227, (1829).

3 *As. Res.*, XVIII, pt. 1, p. 127, (1833); abstract in *Glean. Sci.*, I. p. 28, (1829).

4 *Madras Jour. Lit. Sci.*, XI, pp. 44-46, (1840); and *Jour. Roy. As. Soc.*, VII, pp. 212-214, (1843).

5 *Jour. As. Soc. Beng.*, XIII, pp. 992-995, 1002, (1844).

6 *Edin. New Phil. Jour.*, LIII, pp. 277-279, (1852).

7 *Rec. Geol. Surv. Ind.*, XII, pp. 73, 74, (1879).

8 *Ibid.*, pp. 99, 100.

9 *Rec. Geol. Surv. Ind.*, XVI, pp. 116-118, (1883).

Manual of the Geology of India, published in 1887, gave a summary of what was then known about the Indian manganese minerals. To this work I shall refer as Mallet's Mineralogy. After this, two important papers entitled 'The Manganese-iron and Manganese-ores of Jabalpur'[1] and 'The Manganiferous Iron and Manganese ores of Jabalpur'[2], respectively, were written by P. N. Bose, then of the Geological Survey of India. The former paper deals with the economic results of an examination of the deposits round Gosalpur and Sihora in the Jabalpur district, Central Provinces, and the second with their geological occurrence and origin. My own work has been summarized in Dr. Holland's Review of Mineral Production and in his General Reports on the work of the Geological Survey of India[3]; whilst I have so far published the following papers relative to the Indian manganese-ore deposits :—

1. Analyses of Manganese ores.[4]
2. 'A new form of blue Amphibole from Central India.'[5]
3. 'An unusual occurrence of Common Salt.'[6]
4. 'Notes on the Petrology and Manganese-Ore Deposits of the Sausar Tahsil, Chhindwára district, Central Provinces.'[7]
5. 'On Manganite from the Sandur Hills.'[8]
6. 'On the Association of Gibbsite with Manganese-ore from Talevadi, Belgaum district, and on Gibbsite from Bhekowli, Satara district.'[9]
7. 'Manganese in India.'

Of these, the last-named paper was published in the Transactions of the Mining and Geological Institute of India, Vol. I, pp. 69-131 (discussion pp. 221-233). Besides various woodcuts and photographs of manganese mines it contains three maps. It is at present out of print, but is being reprinted and will probably be available again before this Memoir. Those who require only a brief outline account of Indian manganese-ore deposits, I would refer to the paper mentioned rather than to the present Memoir.

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1 *Rec. G. S. I.*, XXI, pp. 71-89, (1888).
2 *Op. cit.*, XXII, pp. 216-226, (1889).
3 *Rec. G. S. I.*, XXXII, pp. 56-59 and 144-146, (1905); XXXIII, pp. 94-100, (1906); XXXV, pp. 22, 23, 38-40, (1907).
4 *Op. cit.*, XXXI, pp. 47, 48, (1904).
5 *Ibid.*, pp. 235, 236.
6 *Ibid.*, p. 237.
7 *Op. cit.*, XXXIII, pp. 159-220, (1906), with map and photo-micrographs.
8 *Ibid.*, pp. 229-232, with photo.
9 *Op. cit.*, XXXIV, pp. 167-171, (1906), with photo-micrographs.

Literature of foreign manganese-ore deposits.

It was my original intention to render this Memoir more complete and generally useful by including in it a brief account of the foreign deposits of manganese-ore. On going into the question, however, I found the literature about this mineral to be so voluminous and the deposits so numerous, that to do justice to the subject it would be necessary to increase the size of this work much beyond its present dimensions. Consequently I have decided to omit any account of the foreign deposits except for comparative references in the text. Instead, however, I will give a short bibliography, which makes no pretension to completeness, but gives some of the more important papers dealing with this mineral. By looking up these references, especially those dealing with the subject in a general way, it will be possible for anyone to obtain access to practically all the available literature.

By far the best general account of the manganese-ore deposits of the world is contained in A. W. Stelzner and A. Bergeat's 'Die Erzlagerstätten', the first of the references classified under 'general' below. In this work the deposits are classified according to their origin and mode of occurrence, whilst copious references are given to the literature of the subject.

List of Literature of the Foreign Manganese-ore Deposits.

General.

1. A. W. Stelzner & A. Bergeat, 'Die Erzlagerstätten', pp. 239-264, (1904); 571-576, (1905-06), Leipzig.

2. E. Fuchs and L. de Launay 'Traité des Gîtes Minéraux et Métallifères', II, pp. 1-32, (1893), Paris.

3. R. Beck & W. H. Weed, 'The Nature of Ore Deposits', pp. 104-111, 198, 199, 535-538, (1905), New York.

4. Léon Demaret. 'Les principaux gisements des Minerais de Manganèse du Monde', *Annales des Mines de Belgique*, X, pp. 809-901, (1905).

5. J. D. Weeks & J. Birkinbine. articles on Manganese in the '*Mineral Resources of the United States*' from 1885 to date, U. S. Geol. Surv.

6. Articles on Manganese in the annual volumes of 'The Mineral Industry', 1891 to date, New York.

7. F. P. Dunnington, 'On the formation of deposits of Oxides of Manganese', *Am. Jour. Sci.*, 3rd series, XXXVI, pp. 175-178, (1888).

8. R. A. F. Penrose, Jr., The Chemical Relation of Iron and Manganese in Sedimentary Rocks', *Jour. of Geol.*, I, pp. 356-370, (1893).

9. G. Bertrand, 'Le Manganèse dans la nature', *Revue Générale de Chimie*, VIII, pp. 205-217, (1905).

Arranged according to continents and countries.

Africa.

Cape Colony:—

1. *Mining Journal*, 21st April, 1906, p. 509.

America.

Brazil :—

1. J. C. BRANNER, 'The Manganese-Deposits of Bahia and Minas, Brazil', *Trans. Amer. Inst. Min. Eng.*, XXIX, pp. 756-770, (1900).
2. H. K. SCOTT, 'The Manganese Ores of Brazil', *Jour. Iron Steel Inst.*, No. I of 1900, pp. 179-218.
3. O. A. DERBY, 'On the Manganese Ore Deposits of the Queluz (Lafayette) District, Minas Geraes, Brazil', *Amer. Jour Sci.*, XII, pp. 18-32, (1901).
4. J. BIRKINBINE (O. A. DERBY and others), *Min. Res. U. S.*, 1898-99, pp. 140-142; 1901, pp. 140-143.
5. H. K. SCOTT, 'O Manganez no Brazil', *Jornal do Commercio*, Rio de Janeiro, 1902, 58 pages.
6. O. A. DERBY, 'O Manganez em Nazareth', *Boletim da Secretaria de Agricultura .....do Estado da Bahia*, V, pp. 62-65, (1905).
7. M. A. LISBOA, 'Report on the Manganese Ore Deposit of Morro da Mina', *Brazilian Engineering and Mining Review*, III, Nos. 6 and 7; reprint of 21 pages, received 1907.

Canada :—

1. R. A. F. PENROSE, JR., 'Manganese: Its Uses, Ores, and Deposits', *Ann. Rep. Geol. Surv. Arkansas* for 1890, Vol. I, pp. 496-538.
2. E. D. INGALL, Section on Manganese, *Ann. Rep. Geol. Surv. Canada for* 1902-3, pp. 148s-169s.

Chile :—

1. WEEKS & BIRKINBINE, *Min. Res. U. S.*, 1894-95, pp. 439-443; 1898-99, pp. 142-147.
2. BECK & WEED, p. 110, (1905).

Columbia :—

1. E. J. CHIBAS, 'The Manganese-Deposits of the Department of Panamá, Republic of Columbia', *Trans. Amer. Inst. Min. Eng.*, XXVII, pp. 63-76, (1897).
2. E. G. WILLIAMS, 'The Manganese Industry of the Department of Panama, Republic of Columbia', *Op. cit.*, XXXIII, pp. 197-234, (1902).

Cuba :—

1. WEEKS & BIRKINBINE (E. J. Chibas), *Min. Res. U. S.*, 1891, pp. 142-143; 1896-97, pp. 312-3; 1899-1900, pp. 146-9.
2. H. C. BROWN, Civil Report of the Military Governor of Cuba, Vol. V, part II, (quoted in the *Min. Res. U. S.*).
3. A. C. SPENCER, 'The Manganese deposits of Santiago Province, Cuba', *Engin. Min. Jour.*, 23rd Aug. 1902, pp. 247-8.

Mexico :—

1. E. HALSE, 'Notes on the Occurrence of Manganese Ore near Mulegé, Baja California, Mexico', *Trans. North of Eng. Inst. Min. & Mech. Eng.*, XLI, pp. 302-307, (1892).
2. J. G. AGUILERA, 'The Geographical and Geological Distribution of the Mineral Resources of Mexico', *Trans. Am. Inst. Min. Eng.*, XXXII, p. 505, (1902).

United States of America :—

1. R. A. F. PENROSE, 'Manganese: Its Uses, Ores, and Deposits', *An. Rep. Geol. Surv. Arkansas* for 1890, Vol. I, (1891).
2. F. L. NASON, 'The Franklinite-Deposits of Mine Hill, Sussex County, New Jersey', *Trans. Amer. Inst. Min. Eng.*, XXIV, pp. 121-130, (1894).
3. J. F. KEMP, 'The Ore Deposits of the United States and Canada', 4th edit., pp. 416-422, (1901).
4. T. L. WATSON, 'Geological Relations of the Manganese Ore-Deposits of Georgia', *Trans. Am. Inst. Min. Eng.*, XXXIV, pp. 207-253, (1903).
5. J. E. WOLFF, 'Zinc and Manganese Deposits of Franklin Furnace N. J.', *U. S. Geol. Surv.. Bull* No. 213, pp. 214-217, (1903)

6. WEEKS & BIRKINBINE, *The Mineral Resources of the United States'*, 1885 to date.
7. 'The Mineral Industry', Vol. I (1891) to date.

Asia

Borneo :—

1. A. DIESELDORFF, 'Neue Manganerz-Vorkommen in Britisch Nord-Borneo', *Zeitsch. f. prak. Geol.*, XIV, pp. 10-11, (1906); abstract in *Trans. Min. Geol. Inst. Ind.*, I, p. 132, (1906).

Cyprus :—

1. A. GAUDRY, 'Géologie de l'île de Chypre', *Mém. Soc. géol. de France*, 2nd series, VII, pp. 191-2, (1860).

Japan :—

1. 'The Mineral Industry', X, p. 446, (1901).

Java :—

1. 'The Mineral Industry', X, p. 446, (1901).

Turkey-in-Asia :—

1. 'The Mineral Industry', VII, p. 504, (1898).
2. L. DOMINIAN, 'Mining in Turkey', *Eng. Min. Jour.*, 4th Aug. 1904, p. 185.

Australasia.

New Zealand :—

1. WEEKS, *Min. Res. U. S.*, 1893, p. 154.

Queensland :—

1. L. C. BALL, 'Some Manganese Deposits in the Gingin, Degilbo and Warwick Districts', *Geol. Surv. Queensland*, *Publication* No. 189, pp. 1-10, (1904).
2. 'The Mineral Industry', XI, p. 464, (1902).

Europe.

Austria :—

1. B. WALTER, 'Die Erzlagerstätten der südlichen Bukowina', *Jarhb. d. k. k. geol. Reichsanst*, XXVI, pp. 373-382, (1876).
2. L. K. MOSER, 'Manganerzvorkommen von Kroglje bei Dolina in Istrien', *Verhandl. d. k. k. geol. Reichsanst.*, Vienna, 1903, pp. 380-381.

Bosnia :—

1. B. WALTER, 'Beitrag zur Kenntniss der Erzlagerstätten Bosniens', pp. 44-72, (1887).
2. Other papers cited by Stelzner & Bergeat, p. 252.
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Nature of Manganese and its Distribution in Nature [1].

Nature of Manganese.

Manganese in the elementary form is a metal belonging to the manganese-iron group of elements, comprising manganese, iron, cobalt, and nickel, which, owing to their more or less similar chemical properties, often occur in association in Nature. When pure, metallic manganese is said to be of a greyish white colour. It is, for a metal, extremely hard, cutting both glass and hardened steel. In the following table some of its physical constants are compared with those of the other members of the group.[2]

TABLE 1.

Physical constants of the manganese-iron group of elements.

	Symbol.	Atomic weight.	Specific gravity.	Atomic volume.	Specific heat.	Melting point.
						C.
Manganese	Mn.	55·0	8·00	6·9	0·110	1245°
Iron	Fe.	55·9	7·86	7·1	0·114	1600°
Nickel	Ni.	58·7	8·80	6·7	0·108	1470°
Cobalt	Co.	59·0	8·80	6·7	0·104	1530°

[1] See also the very interesting work by R. A. F. Penrose, Jr., *An. Rep. Geol. Surv. Arkansas for* 1890, Vol. I, 'Manganese : Its Uses, Ores and Deposits', pp. 1 to 56 ; and a more recent paper by G. Bertrand entitled 'Le Manganèse dans la nature', published in the *Revue Générale de Chimie*, VIII, pp. 205 to 217, (1905).

[2] Roberts-Austen, 'An Introduction to the Study of Metallurgy', pp. 72, 73, (1898), with severa alterations in accordance with later research

Origin of the word 'manganese'.

Manganese does not occur in nature in the metallic condition, but only in combination, usually in the form of oxide, manganate, carbonate, or silicate. In the form of oxide manganese has been known from very early times. Pliny considered the oxide to be a form of magnetite or lodestone, calling both substances *magnes* manganese oxide being of the feminine gender and not attracting iron[1]. In the middle ages both the black oxide of manganese and the white oxide of magnesium were known as *magnesia*, being distinguished as *magnesia nigra* and *magnesia alba*, respectively. In the *Dictionnaire de Chymie* of Macquer[2] published in 1778, that is, just after the recognition of manganese as a new element, three sorts of magnesia are distinguished. These are *magnésie calcaire, magnésie d'Epsom and magnésie noire*, the last named being even then also known as *manganèse* and *savon de verre*; the latter name refers to the property of manganese peroxide of removing from glass the greenish colour due to the presence of ferrous iron. It is not known how or when the word *manganese* originated. It is supposed by some to have been derived from *magnesia nigra* by metathesis or interchange of letters. In Latin manuscripts of the sixteenth century it appears in the form *lapis manganensis*, and still later as *manganesium*[3]. In his 'Opuscula Physica et Chemica', (1788)[4], Bergmann, in giving an account of the then newly discovered metal, gives it the Latin name of *magnesium*, from *magnesia nigra*. According to Bertrand[5], Guyton de Morveau proposed to translate this term *magnesium* into French not as *magnésie*, as this would have caused confusion, but as *manganèse*. Since then the latter term has been used in science, the English form of the word being, of course, *manganese*.

Recognition as a new element.

Until 1740, when Pott [6] showed that black oxide of manganese does not contain iron, whilst it yields a definite series of salts, the oxides of manganese and iron were confounded one with the other. But Pott did not suggest that oxide of manganese contains a metal. Indeed, according to Bertrand [7], Bergmann was the first to give serious reasons for

1 Roscoe & Schorlemmer, 'Treatise of Chemistry', Vol. II, Part II, p. 1, 1879.
2 Quoted by G. Bertrand, *loc. cit.*, 205.
3 Roscoe & Schorlemmer, *loc. cit.*, p. 2.
4 Quoted by Bertrand, *loc. cit.*, p. 206.
5 *Loc. cit.*, p. 206.
6 'Examen chymicum magnesia vitrariorum, Germanis Braunstein, (Roscoe & Schorlemmer, *loc. cit.*, p. 2.)
7 *Loc. cit.*, p. 205.

classifying manganese oxide amongst the calxes rather than amongst the earths. At Bergmann's request, Scheele experimented on manganese, and, although he did not succeed in isolating the metal, he discovered sufficient of the characters of its compounds to show the existence of a new element[1]. Two years later (1776) Gahn succeeded in isolating the metal[2].

Distribution in Nature.

Of all the elements manganese is one of the most widely distributed throughout the three kingdoms of Nature; it is to a large extent co-extensive with iron in its occurrence.

Manganese in the mineral kingdom.

The total number of well-defined minerals yet found in the earth's crust, either in its rocks or its mineral deposits, is in round numbers about 1,000. Of these about 130 to 140 contain manganese as an essential constituent, whilst many more often contain it in less important quantities. The consequence is that most of the rocks of the earth's crust contain manganese, though usually in small proportion only. According to F. W. Clark[3] 0·10 per cent. of the earth's crust consists of manganese protoxide (MnO), manganese ranking as the fifteenth most important element in this respect. As the result of the decomposition and denudation of the earth's surface by meteoric agencies, its various constituents are carried either in suspension or solution to the sea. It has been estimated by Murray[4] that one cubic mile of average river water contains in solution 5,703 tons of manganese sesquioxide (Mn_2O_3), and that 6,524 cubic miles of river water are annually discharged into the sea[5]. This means that about 37,000,000 tons of Mn_2O_3, containing nearly 26,000,000 tons of metallic manganese, are brought every year by rivers into the oceans. This process has presumably been going on for untold ages, so that now we should expect to find large quantities of manganese salts in solution in sea-water. This, however, is not the case, and it seems to me that in this disappearance of manganese from solution in the water we have the

1 Stockholm Memoirs, 1774 (Kongl. Svenska Vetenkaps-Akademiens Handlingar) (Penrose); also see 'The Chemical Essays of Charles William Scheele translated from the Transactions of the Academy of Sciences at Stockholm' by Thomas Beddoes, London (1786), Essay V.

2 Roscoe & Schorlemmer, Vol. II, Part II, p. 2.

3 *U. S. Geol. Surv. Bulletin* No. 228, p. 19, (1904).

4 *Scottish Geographical Magazine*, III, p. 77, (1887).

5 *Op. cit.*, IV, p. 41, (1888).

explanation of the presence of the large numbers of concretions of manganese oxide that are so abundantly dredged up in nearly all deep-sea exploration work from the bottom of the ocean[1]. Manganese is also sometimes found in meteorites.

Manganese in the vegetable kingdom.

It is well-known that plants obtain through their roots a certain proportion of their nourishment by the absorption from the soil of water containing mineral substances in solution. In view of the ease with which the manganese minerals are known to undergo decomposition and to pass into solution in surface waters, it is not surprising to find that nearly all plants seem to contain a certain proportion of manganese, presumably obtained from the soil through the medium of their roots. The work on this subject is well summarized by Bertrand in the paper already cited[2]. It seems that Scheele was the first to detect manganese in plants, finding it in the ashes of the wild cummin and wood. Later, in 1849, Herapath found manganese in the ashes of the radish, turnip, beetroot and carrot; then Richardson found it in the ashes of the sugarcane and Salm Hortsdar in those of oats. In 1852 Liebig detected both iron and manganese in the ashes of tea and coffee. Since then the amounts of manganese in many plants have been estimated, and this element has been recognized as occurring in potato, wheat, grapes, and many other vegetables, fruits, cereals, and wood, in addition to those already mentioned. When working in the field on the manganese-ore deposits I was not aware of the universal distribution of manganese in plants, and collected specimens of wood from trees that were growing actually on the manganese-ore, with the idea of seeing if they had taken up any manganese. I also collected some specimens of bamboo from the top of a laterite hill in the Bálághát district in the Central Provinces to serve as a blank so to speak; for this laterite did not contain any visible manganese oxide. I only had time to deal with this sample. It was divided into short lengths, the outside cut off and rejected, and then 533·5 grammes of the wood were incinerated in a platinum dish with the production of 8·8 grammes of ash of a bluish green colour, thus testifying to the presence of manganese in the bamboo. In order to find out if manganese is an essential constituent of plants and not an accidental one, Bertrand made some experiments on the latex of the tree from Tonkin known as *Rhus succedanea*. It appears that when the bark of that tree is incised a thick,

1 See especially:—*Challenger Reports*, Vol. on Deep Sea Deposits, (1891).
2 P. 212.

whitish juice exudes, which rapidly turns first brown and then black on exposure to the air. This latex consists of laccase, laccol, and water. The laccase is in solution in the water and the laccol is in a finely divided state as an emulsion. The experiments show that the laccase contains manganese and that the latter acts as a carrier of oxygen from the atmosphere to the laccol. Laccol is not present in all plants, but its place is very often taken by analogous chemical substances such as tannin, boletol, and hydroquinone. It appears from these experiments that the presence of manganese is in all probability not fortuitous, but of vital importance to the plant, and connected with the extraction of oxygen from the air, whenever this is necessary for the causation of various chemical changes necessary to the vital activity of the plant.

Manganese in the animal kingdom.

Since all animals live either directly on plants, or directly or ultimately on other animals that eat plants, one would expect manganese to be found in animal tissues. This is found to be the case; but the presence of manganese in the animal kingdom does not seem to have been so thoroughly investigated as in the case of the vegetable kingdom. Bertrand, in the paper already mentioned, mentions its detection by Vauquelin in hair, Berzelius in bone, Chevreul in mutton grease, Oidtmann in the liver and human spleen; whilst, according to Millon, du Buisson, and Riche, it occurs in small quantities, namely 1 to 5 milligrammes per kilogramme, in the blood of human beings and other mammals. The proportion of manganese to iron in the human body is said to be 1 to 20 [1].

[1] Penrose, *loc. cit.*, p. 2.

CHAPTER II.

MINERALOGY.

General.

Distribution of manganese in minerals and rocks—Colours of manganese minerals—Occurrence of manganese minerals—List of known manganese minerals—List of Indian manganese minerals—List of associated non-manganiferous minerals—New species and varieties.

Wide distribution of manganese in minerals and rocks.

The total number of well-defined minerals yet found in the earth's crust, both in its rocks and in its mineral deposits, is in round numbers about one thousand. Of these more than 100 contain manganese as an essential constituent, whilst many more frequently contain it in less important quantities. The consequence is that most of the rocks of the earth's crust contain this element, though usually only in small proportion; and according to F. W. Clark[1] 0·10 per cent. of the earth's crust consists of manganese protoxide (MnO), manganese ranking as the fifteenth most important element in this respect.

Colours of manganese minerals.

There are many minerals that ordinarily do not contain this element in appreciable amount. Under somewhat rare circumstances, such as when such minerals have been formed in the presence of large quantities of manganese compounds, as in the metamorphism of manganiferous sediments, a small quantity of manganese may enter into the composition of the mineral with a most remarkable effect on the colour, and therefore frequently on the pleochroism, of the mineral, without affecting its other properties appreciably. As a very good example of this winchite may be mentioned; this is practically a variety of tremolite, a colourless mineral, but contains small quantities of manganese, iron, and alkalies, in addition to the usual constituents. The winchite, instead of being white or colourless, is blue or lavender in the hand-specimen, and shows very beautiful pleochroism, under the microscope, in shades of lilac and blue. In the same way blanfordite is a pyroxene containing a certain quantity of manganese and alkalies; in the hand-specimen it is of a deep crimson colour, whilst under the microscope it shows as beautiful pleochroism, in shades of blue, carmine, and lilac, as has been noticed

[1] *U. S. Geol. Surv., Bulletin* No. 228, p. 19, (1904).

for any known mineral. Similarly the manganese-micas show various shades of pink, delicate green, orange, and lilac-brown, in thin scales examined under the microscope. As other examples of the effect on the colour of a mineral may be mentioned the manganese-epidote, piedmontite, and the manganese-sphene, greenovite. Excepting the oxides, which are usually of some shade of black or dark grey, the minerals of manganese usually show some variety of blue, pink, lilac, or crimson, whilst orange and yellow tints are found in the garnets. Other colours, such as green and brown, are also found in manganese minerals, but they are of much rarer occurrence. The colour of a given mineral depends, of course, on the other constituents besides the manganese, so that it is difficult to say which colours are specially due to the manganese. Thus in winchite and blanfordite, mentioned above, the soda present has perhaps partly contributed to the colour. But a comparison of the colours of minerals containing manganese with those of minerals otherwise similar but practically free from this constituent points to the fact that the colours specially due to the presence of manganese in a mineral are red, pink, and lavender, and allied tints. Rose quartz and amethyst may also be cited as exhibiting in a remarkable manner the colour effects produced by manganese; for both these varieties of quartz have been shown to contain this element [1].

The occurrence of manganese minerals.

As regards mode of occurrence manganese minerals exhibit the greatest variety; for they are found in igneous, metamorphic, and sedimentary rocks, and in mineral veins traversing these rocks, as original minerals formed at the same time as the enclosing rock or vein-filling. In all these rocks and veins they may also be found as secondary minerals formed by the chemical alteration of pre-existing minerals in the rocks or veins, or by the introduction of manganese salts in solution from without. Moreover, by the weathering of these minerals when they are exposed at the surface secondary manganese minerals are frequently formed. The minerals most frequently found are the oxides, which occur in metamorphic and sedimentary rocks and in veins, and perhaps rarely in igneous rocks[2]. The carbonates are not found in igneous rocks, but are found in all the others. Silicates are especially characteristic of the metamorphic rocks; they are found somewhat less

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[1] Rose quartz, see page 212; amethyst, see M. Berthelot, *Comptes rendues*, CXXXXIII, pp. 477 to 488, (1906).

[2] O. A. Derby has ascribed an igneous origin to an ore or rock composed of polianite (MnO_2) and spessartite-garnet. *Amer. Jour. Sci.*, XII, pages 26, 30. (1901.)

often in igneous rocks, rarely in mineral veins, and probably never in sedimentary rocks. The niobates, tantalates, and tungstates, are found either in igneous [1] veins, whilst the phosphates, arsenates, and antimonates, probably occur in both igneous veins and metamorphic rocks. The titano-silicates are also found in igneous and metamorphic rocks. Of the large number of manganese minerals known, only a moderate proportion has been found in India. Taking into account, however, the considerable variety of the Indian manganese minerals yet found—including members of the groups of oxides, manganates, carbonates, silicates, phosphates, arsenates, niobates, and tungstates—, and the fact that the list of Indian manganese minerals is being constantly extended, one may expect to find almost any of the manganese-bearing minerals met with in other parts of the world. Consequently I propose to give here a list of all the well-defined minerals containing a considerable proportion of manganese, together with the formula, crystal system, specific gravity, and hardness of each. The figures given in this list as well as the formulæ, are almost all of them taken from the sixth edition of Dana's System of Mineralogy, its Supplement, and Appendix.

TABLE 2.

List of known manganese minerals with their chief properties.

Name.	Formula.	Crystalline system.	Specific gravity.	Hardness.
Sulphides—				
Alabandite .	MnS	I. Tetrahedral.	3·95–4·04	3·5–4
Hauerite .	MnS_2	I. Pyritohedral	3·46	4
Chlorides—				
Scacchite .	$MnCl_2$	..	..	..
Oxides—				
Manganosite .	MnO	I. .	5·18	5–6
Pyrophanite .	$MnO.TiO_2$	III. Rhombtetartohedral.	4·54	5
Bixbyite .	$FeO.MnO_2$ . . .	I. .	4·95	6–6 5

[1] Including 'aqueo-igneous' veins.

TABLE 2—*contd.*

List of known manganese minerals with their chief properties.

Name.	Formula.	Crystalline system.	Specific gravity.	Hardness.
Senaite	$(Fe,Pb)O.2(Ti,Mn)O_2$	III. Tri-rhombohedral.	4·78–5·3	6
Dysluite	$(Zn,Fe,Mn)O.(Al,Fe)_2O_3$	I.	4–4·6	7·5—8
Manganmagnetite.	$(Fe,Mn)O.Fe_2O_3$	I.	5·06	(5·5–6·5)
Franklinite	$(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$	I.	5·07–5·22	5·5–6·5
Jacobsite	$(Mn,Mg)O.(Fe,Mn)_2O_3$	I.	4·75	6
Hausmannite	$MnO.Mn_2O_3$	II.	4·73–4·86	5–5·5
Manganoferrite (artificial).	$(Fe,Mn)_3O_4$	..	...	..
Crednerite	$3CuO.2Mn_2O_3$	V.	4·9–5·1	4·5
Vredenburgite	$3Mn_3O_4.2Fe_2O_3$	..	4·74–4·84	6·5
Sitaparite	$9Mn_2O_3.4Fe_2O_3.MnO_5.3CaO$	..	4·93–5·09	7
Braunite	$3Mn_2O_3.MnSiO_2$	II.	4·75–4·82	6–6·5
Polianite	MnO_2	II.	4·83–5·03	6–6·5
Pyrolusite	MnO_2	IV (?).	4·73–4·86	2–2·5
Manganite	$Mn_2O_3.H_2O$	IV	4·2–4·4	4
Manganbrucite	$(Mg,Mn)OH_2O$.	III Rhombohedral.	(2·38–2·4)	(2·5)
Pyrochroite	$MnO.H_2O$	Ditto	3·26	2·5
Chalcophanite	$(Mn,Zn)O.2MnO_2.2H_2O$.	Ditto	3·91–4·01	2·5
Manganates—				
Hollandite	$m(Ba,Mn)_2MnO_5 + nFe_4(MnO_5)_3$.	VI (?)	4·95	4·6
Coronadite	R_2MnO_5, with R = chiefly Mn, Pb.	Fibrous	5·246	4

TABLE 2—*contd.*

List of known manganese minerals with their chief properties.

Name.	Formula.	Crystalline system.	Specific gravity.	Hardness.
Psilomelane	H_4MnO_5, with H replaced by Fe, Mn, Ni, Co, Mn, Ba, Ca, K, etc.	Amorphous	3·7–4·7	5–6
Beldongrite	$6Mn_3O_5.Fe_2O_3.8H_2O$	Ditto	3·22	4
Wad	Impure Mn oxides passing into psilomelane.	Ditto	3·0–4·3	1–6
Carbonates—				
Mangancalcite	$(Ca,Mn)CO_3$	III. Rhombohedral.	2·78–2·84	(3)
Mangandolomite.	$(Ca,Mg,Mn)CO_3$	Ditto	2·83–2·89	(3·5–4)
Ankerite	$CaCO_3.(Mg,Fe,Mn)CO_3$	Ditto	2·95–3·1	3·5–4
Mangansiderite (oligonite).	$(Fe,Mn)CO_3$	Ditto	3·71–3·74	(3·5–4)
Rhodochrosite	$MnCO_3$	Ditto	3·45–3·6	3·5–4·5
Metasilicates—				
Violan	Manganiferous diopside	V.	3·21–3·27	...
Anthochroite	Manganiferous diopside	V.	...	5–6
Blanfordite	Probably allied to violan	V.	3·15	..
Manganhedenbergite.	$Ca(Fe,Mn)(SiO_3)_2$	V.	3·55	(5–6)
Asteroite	Var. of manganhedenbergite	V.	...	...
Schefferite	$(Ca,Mg)(Fe,Mn)(SiO_3)_2$	V.	...	...
Jeffersonite	$(Ca,Mg)(Fe,Mn,Zn)(SiO_3)_2$	V.	3·36	...

TABLE 2—*contd.*

List of known manganese minerals with their chief properties.

Name.	Formula.	Crystalline system.	Specific gravity.	Hardness.
Urbanite	(Ca, Mg,Mn) SO + 2Na Fe‴ $(SiO_3)_2$.	V.	3·52–3·53	5–6
Manganpectolite.	$H_2O.Na_2O.4(Ca,Mn)O.6SiO_2$	V.	2·84	5
Låvenite	(Na_4,Ca_2,Mn_2,Zr) $[(Si,Zr)O_3]_2$.	V.	3·51–3·55	6
Rhodonite	$MnSiO_3$	VI.	3·4–3·68	5·5–6·5
Bustamite	(Mn,Ca)SiO_3		..	...
Fowlerite	(Mn,Zn,Fe,Ca)SiO_3	VI.	3·67	..
Babingtonite	(Ca, Fe,Mn)SiO_3 and $Fe_2(SiO_3)_3$.	VI.	3·35–3·37	5·5–6
Hexagonite	Tremolite containing a little Mn.	V.	3·0	...
Winchite	Tremolite containing Fe, Na, K, and Mn.	V.	2·98–3·08	..
Dannemorite v. silfbergite.	(Fe,Mn,Mg)SiO_3	V.	3·45	5·5
Richterite	$[(K,Na)_2,Mg,Ca,Mn]SiO_3$	V.	3·09	...
Astochite	(Mg,Mn,Ca)SiO_3 and $(Na,K,H)_2SiO_3$.	V.	3·05–3·10	...
Gamsigradite	Manganese-hornblende	V.	..	..
Barkevikite	Mn-amphibole near glaucophane.	V.		
Intermediate Silicates—				
Barysilite	$Pb_3Si_2O_7$ with Mn, Ca, and Mg.	III.	6·11–6·55	3
Ganomalite	$Pb_3Si_2O_7.(Ca,Mn)_2SiO_4$	II.	4·98–5·74	3

TABLE 2—*contd.*

List of known manganese minerals with their chief properties.

Name.	Formula.	Crystalline system.	Specific gravity.	Hardness.
Orthosilicates—				
Helvite	$(Mn,Fe)_2(Mn_2S)Be_3(SiO_4)_3$	I. Tetrahedral.	3·16–3·36	6–6·5
Danalite	$(Fe,Zn,Mn)_2$ [$(Zn,Fe)_2S$] $Be_3(SiO_4)_3$.	I.	3·35–3·43	5·5–6
Mangan-grossularite	$3(Ca,Mn)O.Al_2O_3.3SiO_2$	I.	3·24	..
Spessartite	$3MnO.Al_2O_3.3SiO_2$	I.	4·0–4·3	6·5–7·5
Spandite	$3(Ca,Mn)O.(Al,Fe)_2O_3.3SiO_2$.	I.	3·8–4·1	6·5–7·5
Allochroite, Polyadelphite, Aplome, Rothoffite	Manganiferous varieties of andradite, $3CaO.Al_2O_3.3SiO_2$.	I.	..	..
Partschinite	$(Mn,Fe)_3Al_2Si_3O_{12}$	V.	4·01	6·5–7
Glaucochroite	$CaMnSiO_4$	IV.	3·41	6
Hortonolite	$(Fe,Mg,Mn)_2SiO_4$	IV.	3·91	6·5
Knebelite	$(Fe,Mn)_2SiO_4$	IV.	3·9–4·17	6·5
Tephroite	Mn_2SiO_4	IV.	4–4·12	5·5–6
Roepperite	$(Fe,Mn,Zn)_2SiO_4$	IV.	3·95–4·08	5·5–6
Trimerite	$(Mn,Ca)_2SiO_4.Be_2SiO_4$.	VI (pseudo-Rhombohedral).	3·47	6–7
Troostite	$(Zn,Mn)_2SiO_4$	III. Rhombohedral.	3·89–4·18	5·5
Friedelite	$H_7(MnCl)Mn_4(SiO_4)_4$.	Ditto	3·06–3·07	4–5
Pyrosmalite	$H_7[(Fe,Mn)Cl](Fe,Mn)_4(SiO_4)_4$.	Ditto	3·06–3·19	4–4·5
Basic Silicates—				
Mangan-vesuvianite.	Silicate of Ca,Al,Fe, with Mn.	IV.	(3·35–3·45)	(6·5)
Mangan-andalusite.	$(Al,Mn)_2O_3.SiO_2$	IV.	(3·16–3·20)	(7·5)

TABLE 2—*contd.*

List of known manganese minerals with their chief properties.

Name.	Formula.	Crystalline system.	Specific gravity.	Hardness.
Basic Orthosilicates—				
Withamite .	Epidote with small quantity of Mn.	V. .	3·14	6–6·5
Piedmontite .	$Ca_2(AlOH)(Al,Mn,Fe)_2(SiO_4)_3$	V. .	3·40	6·5
Hancockite .	$(Pb,Ca,Sr,Mn)_2[(Al,Fe,Mn).OH](Al,Fe,Mn)_2(SiO_4)_3$	V. .	4·03	..
Axinite .	Boro-silicate of Al, Fe, Ca, Mn.	VI.	3·27–3·29	6·5–7
Acid Orthosilicate-				
Harstigite .	$H_7(Ca,Mn)_{12}Al_3Si_{10}O_{40}$.	IV. .	3·05	5·5
Subsilicates—				
Leucophœnicite (manganese-humite).	$H_2(Pb,Mn,Ca,Zn)_7Si_3O_{14}$.	V.(?)	3·85	
Ilvaite .	$HCa\,Fe''_2\,Fe'''Si_2O_9$ with often Mn	IV. .	3·99–4·05	5·5–6
Ardennite .	$H_5Mn_4Al_4VSi_4O_{23}$	IV. .	3·57–3·62	6–7
Långbanite .	$mSb_2O_3.nFe_2O_3.pMn''(Mn^{iv}_2Si)O_3$.	III. Rhombohedral.	4·65–4·92	6·
Kentrolite .	$2PbO.Mn_2O_3.2SiO_2$.	IV. .	6·19	5
Carpholite .	$H_4MnAl_2Si_2O_{16}$ . .	V. .	2·93	5–5·5
Hydrous Silicates--				
Inesite . .	$2(Mn,Ca)SiO_2 + H_2O$.	VI. .	3·03	6
Ganophyllite .	$6H_2O.7MnO.Al_2O_3.8SiO_2$.	V. .	2·84	4–4·5
Agnolite .	$H_2Mn_3(SiO_3)_4 + H_2O$.	VI. .	3·05–3·07	5

TABLE 2—*contd.*

List of known manganese minerals with their chief properties.

Name.	Formula.	Crystalline system.	Specific gravity.	Hardness.
Manganophyllite	Biotite with 5-21% MnO.	V.	..	..
Alurgite	A manganese-mica	V.	2·83–3	2·25–3
Roscoelite	Vanadium mica sometimes with Mn.	..	2·92–2·94	..
Caswellite (altered mica).	Ca, Mg, Mn, Fe, Al, silicate	..	3·54	2·5–3
Other manganese-micas.				
Salmite	Manganesian chloritoid	V or VI.	3·38	..
Masonite	Ditto	Ditto	3·45	...
Ottrelite	$H_2(Fe,Mn)Al_2Si_2O_9$.	V.	3·3	6–7
Manganchlorite	Silicate of H, Al, Mg, with Mn.	V.	..	...
Strigovite	$H_4(Fe,Mn)_2(Fe,Al)_2Si_2O_{11}$.	..	3·14	...
Marjatskite	Manganese-glauconite	..	...	...
Bementite	$2MnSiO_3.H_2O$	..	2·98	...
Caryopilite	$4MnO.3SiO_2.3H_2O$	..	2·83–2·91	3–3·5
Neotocite	Hydrated silicate of Mn and Fe.	..	2·64–2·8	3–4
Titano-Silicates—				
Greenovite	$CaTiSiO_5$ with Mn	V.	(3·4–3·56)	(5–5·5)
Neptunite	$R'_2 R''TiSi_4O_{12}$, w th R′= Na, K, and R″=Fe, Mn;	...	3·23	5–6

TABLE 2—*contd.*

List of known manganese minerals with their chief properties.

Name.	Formula.	Crystalline system.	Specific gravity.	Hardness.
Hellandite .	$Ca_2 R'''_3(R''O)_3 (SiO_4)_4$, with R'' = Ce, Di, La, Al, Fe, Mn.	..	..	..
Astrophyllite .	$(Na,K)_4 (Fe,Mn)_4 Ti(SiO_4)_4$	IV. .	3·3–3·4	3
Lamprophyllite	Contains Na, Fe, Mn, Ti, and SiO_2.	IV. .	3·45	
Niobates and Tantalates—				
Columbite and Tantalite.	$(Fe,Mn)(Nb,Ta)_2O_6$.	IV. .	5·3–7·3	6
Manganocolumbite.	$MnNb_2O_6.MnTa_2O_6$.	IV. .	6·59	
Manganotantalite.	$MnTa_2O_6$ . . .	IV. .	7·30	
Hielmite .	Stanno-tantalate of Y, Fe, Mn and Ca.	IV. .	5·82	5
Phosphates and Arsenates—				
Berzeliite .	$(Ca,Mg,Mn)_3As_2O_8$	I. .	4·07–4·09	5
Soda-berzeliite	$(Ca,Mn,Na_2)_3As_2O_8$.	I. .	4·21	4–4·5
Caryinite .	$(Pb,Mn,Ca,Mg)_3As_2O_8$?	V(?) .	4·25–4·29	3–3·5
Triphylite .	$Li(Fe,Mn)PO_4$ . .	IV. .	3·42–3·56	4·5–5
Lithiophilite .	$Li(Mn,Fe)PO_4$ . .			
Natrophilite .	$NaMnPO_4$ . . .	IV. .	3·41	4·5–5
Graftonite .	$(Fe,Mn,Ca)_3P_2O_8$	V. .	3·67	5

TABLE 2—*contd.*

List of known manganese minerals with their chief properties.

Name.	Formula.	Crystalline system.	Specific gravity.	Hardness.
Manganapatite	$3Ca_3P_2O_8.CaF_2$ with Mn.	III. Pyramidal.	3·14–3·39	5
Triplite .	$R_3P_2O_8.RF_2$ with R = Fe and Mn.	V.	3·44–3·8	4–5·5
Triploidite .	$(Mn,Fe)P_2O_8.(Mn,Fe)(OH)_2$	V.	3·70	4·5–5
Sarkinite .	$Mn_3As_2O_8.Mn(OH)_2$.	V.	4·17–4·19	4–5
Acid and Basic Phosphates and Arsenates—				
Brackebushite	$(Pb,Fe,Mn)_3V_2O_8.H_2O$?	V?	..	..
Chondarsenite	$Mn_3As_2O_8.3Mn(OH)_2$.	..	..	3
Allactite .	$Mn_3As_2O_8.4Mn(OH)_2$.	V.	3·83–3·85	4·5
Synadelphite .	$2(Al,Mn)AsO_4.Mn(OH)_2$.	V.	3·45–3·50	4·5
Flinkite .	$MnAsO_4.2Mn(OH)_2$.	IV.	3·87	4–4·5
Hematolite .	$(Al,Mn)AsO_4.4Mn(OH)_2$.	III. Rhombohedral.	3·30–3·40	3·5
Arseniopleite .	Hydrated arsenate of Mn, Ca, Pb, Mg and Fe.	Ditto?	..	..
Manganostibiite	$Mn_{10}Sb_2O_{15}$? . .	IV.?	...	...
Hematostibiite	$Mn_8Sb_2O_{13}$? . . .	..	...	..
Ferrostibian .	Hydrated antimonate of Mn and Fe.	V.?	...	4
Stibiatil .	Sb_2O_5, Mn_2O_3, and FeO	V?	...	5–5·5

TABLE 2—*contd.*

List of known manganese minerals with their chief properties.

Name.	Formula	Crystalline system	Specific gravity.	Hardness.
Hydrous Phosphates and Arsenates, etc.—				
Purpurite .	$(Mn'', Fe''')_2P_2O_8 + H_2O$.	IV.?	3·15	4–4·5
Dicknsonite	$3R_3P_2O_8 + H_2O$, with R = Mn,Fe,Na_2, also Ca, K_2, Li_2.	V.	3·34	3·5–4
Fillowite .	$3R_3P_2O_8 + H_2O$ with R = Mn, Fe,Ca, and Na_2.	V.	3·43	4·5
Brandtite .	$Ca_2MnAs_2O_8 + 2H_2O$.	VI.	3·67	5–5·5
Fairfieldite .	$Ca_2MnP_2O_8 + 2H_2O$.	VI.	3·07–3·15	3·5
Reddingite .	$Mn_3P_2O_8 + 3H_2O$	IV.	3·10	3–3·5
Hureaulite .	$H_2Mn_5(PO_4)_4 + 4H_2O$	V.	3·15–3·20	5
Hemafibrite .	$Mn_3As_2O_8.3Mn(OH)_2 + 2H_2O$.	IV.	3·50–3·65	3
Childrenite .	$(Fe,Mn)Al(OH)_2PO_4 + 2H_2O$.	IV.	3·18–3·24	4·5–5
Eosphorite .	$(Mn,Fe)Al(OH)_2PO_4 + 2H_2O$.	IV.	3·11–3·15	5
Antimonates—				
Atopite .	$Ca_2Sb_2O_7$ with often Mn.	I.	5·03	5·5–6
Borates—				
Sussexite .	$H(Mn,Mg,Zn)BO_3$	IV ?	3·42	3
Pinakiolite .	$3MgO.B_2O_3 + MnO.Mn_2O_3$.	IV.	3·88	6

TABLE 2—*concld.*

List of known manganese minerals with their chief properties.

Name.	Formula.	Crystalline system.	Specific gravity.	Hardness.
Sulphates—				
Szmikite .	$MnSO_4 + H_2O$ . .	Amorphous	3·15	1·5
Ilesite . .	$(Mn,Zn,Fe)SO_4 + 4\ H_2O$.	V? .	..	..
Luckite .	$(Fe,Mn)SO_4 + 7H_2O$. .	V. .	..	..
Mallardite .	$MnSO_4 + 7H_2O$ . .	V. .	..	..
Apjohnite .	$MnAl_2(SO_4)_4 + 24H_2O$. .	V. .	1·78	1·5
Bushmanite .	$(Mn,Mg)Al_2(SO_4)_4 + 24H_2O$.	V? .	..	..
Dietrichite .	$(Zn,Fe,Mn)Al_2(SO_4)_4 + 24H_2O$.	V? .	..	2
Tungstates—				
Wolframite .	$(Fe,Mn)WO_4$ . . .	V. .	7·2–7·5	5–5·5
Hübnerite .	$MnWO_4$ . . .	V. .	7·2–7·5	5–5·5

In addition to the minerals mentioned in the foregoing list there are many others that contain manganese in quantities too small to produce any essential change in the characters of the mineral. There are also many minerals containing a considerable proportion of manganese, but which have not been sufficiently investigated for their proper position in the above classification to be ascertainable. Of these the following Swedish arsenates and antimonates of manganese, often containing other bases such as iron, may be mentioned:—basiliite, chlorarsenian, chondrostibian, elfstorpite, lamprostibian, magnetostibian, melanostibian, retzian, rhodarsenian, sjögrufvite.

Of the minerals given in the above list about one quarter have been found in India, a few of the occurrences being open to doubt. The following is a list of the manganese minerals yet found in India :–

TABLE 3.

List of Indian manganese minerals.

Oxides—
- Pyrophanite ?
- Dysluite.
- Manganmagnetite.
- Hausmannite ?
- Vredenburgite ($3Mn_3O_4.2Fe_2O_3$).
- Sitaparite ($9Mn_2O_3\ 4Fe_2O_3.MnO_2.3CaO$).
- Braunite.
- Polianite.
- Pyrolusite.
- Manganite.

Manganates–
- Hollandite.
- Psilomelane.
- Beldongrite ($6Mn_3O_5.Fe_2O_3.8H_2O$).
- Wad.

Carbonates—
- Ankerite.
- Rhodochrosite.

Silicates—
- Blanfordite
- Manganhedenbergite
- Brown and yellow pyroxenes (schefferite ? and urbanite ?)
- Jeffersonite ?
- Rhodonite

} Manganese-pyroxenes.

- Other Mn pyroxenes
- Winchite
- Juddite
- Yellow and greenish grey amphiboles (dannemorite ?)

} Manganese-amphiboles.

- Spessartite
- Spandite
- Grandite (mangan-)
- Aplome
- Calderite

} Manganese-garnets.

- Withamite
- Manganepidote
- Piedmontite

} Manganese-epidotes.

- Ilvaite ?
- Carpholite ?
- Manganophyllite ?

Alurgite ?
Other Mn micas
Manganchlorite ?
Ottrelite.
} Manganese-micas.

Titano-silicates—
Greenovite
Tscheffkinite.

Niobates and tentalates—
Columbite.

Phosphates—
Manganapatite.
Triplite.
A soda-manganese phosphate.

Tungstates—
Wolframite.

For the non-manganiferous minerals associated with the manganese ores of India see the lists on pages 323 to 325. Some of these are, however, of sufficient interest to be considered here. The following is a list of such minerals :—

TABLE 4.

List of certain minerals associated with the Indian manganese-ore deposits.

Graphite.
Chalcopyrite
Pyrite.
Pyrrhotite.
Halite.
Rose quartz.
Amethyst.
Chalcedony and chert.
Opal.
Hematite.
Magnetite.
Martite.
Limonite.
Gibbsite.
Microcline.
Sapphirine.
Lithomarge and Kaolin.
Arsenates
Barytes.

On comparing the list of Indian manganese minerals with the list of known minerals containing this element it will be seen that in some groups the manganese minerals are adequately represented in India, whilst in other groups there are very few or no Indian representatives. The adequately represented groups are the oxides, manganates, carbonates, silicates, niobates, and tungstates ; the sulphides, chlorides, arsenates, antimonates, borates, and sulphates are not represented at all, and the titano-silicates and phosphates only very inadequately. It is in the phosphates, arsenates, and antimonates, that the deficiency of the Indian list is most marked, for, of the total number of 156 minerals given in the list on pages 23 to 33, 33, or nearly a quarter of the whole number, belong to these three allied groups. Considering,

however, that three arsenates, which do not contain manganese, however, and one manganesian phosphate apart from manganapatite, have been found associated with the Indian deposits, it may fairly be expected that future investigation will lead to the discovery of arsenates containing manganese, and of a further number of phosphates.

I now propose to give a short account of each of the minerals given in the foregoing lists of Indian minerals. The notes here given are not intended to be exhaustive, but simply to put on record such facts as have been ascertained about the Indian manganese minerals. Many of the identifications are only provisional requiring the test of complete chemical analysis to confirm them. The result of such analysis will doubtless be to show that many of the minerals distinguished with a query mark in the above list, are not identical with the mineral mentioned, but are closely allied, showing small differences owing to isomorphous replacement of one constituent by another. Moreover, it will be noticed that many of the names given in the list are new to science. They are only a few of the many new species and varieties of manganese minerals that in all probability exist in the Indian manganese-ore deposits. The following is a list of these new species and varieties :—

New species and varieties.

Vredenburgite	Sitaparite	Hollandite
Beldongrite	Blanfordite	Winchite

with one, and perhaps all, of the three arsenates found. Some of the manganese-micas will in all probability be found to be new varieties, whilst the soda-manganese phosphate is probably a new species. Several other minerals that are probably new, have been noticed in the course of the examination of the specimens collected in the Indian manganese deposits; but they are not mentioned here as their characters have not been sufficiently investigated for anything accurate to be stated about them.

It has not yet been found possible to examine carefully some of the well-known minerals like rhodonite and pyrolusite and give figures for their physical characters, such as specific gravity and hardness, based on determinations made on Indian material. Consequently in the case of the more important and commonly occurring minerals, which it is of importance that all engaged in mining manganese-ore should be able to identify, I have taken the figures required from Dana's System of Mineralogy; and when reference is made to this work it is always to the 6th edition, unless otherwise stated.

CHAPTER III.

MINERALOGY—*continued.*

Oxides.

Pyrophanite—Dysluite—Manganmagnetite—Hausmannite—Vredenburgite—Sitaparite—Braunite—Polianite—Pyrolusite—Manganite.

Pyrophanite.

This mineral, of the chemical formula $MnTiO_3$, was originally found at the Harstig manganese mine in Sweden, and has been subsequently recorded as occurring in the Piquiry manganese-ore deposit in Brazil[1]. In the course of the microscopic examination of thin sections of manganese-silicate-rocks from both the Central Provinces and the Kájlidongri mine, Central India, I have several times noticed a mineral of a blood-red colour, non-pleochroic character, and high index of refraction, that may very well be the mineral pyrophanite. It always occurs in such small quantities, just a flake or two, that it is not possible to isolate any and subject it to chemical tests to confirm this supposition as to its nature.

Dysluite.

This mineral, which is a zinc-manganese-spinel of the formula $(Zn,Fe,Mn)O.(Al,Fe)_2O_3$, was found in 1897 by Mr. C. S. Middlemiss of the Geological Survey of India in a felspar-rock containing corundum and sometimes biotite, muscovite, and, in one case, chrysobery. This rock occurs as veins ramifying through the elaeolite-syenite-gneiss between Sivamallai Hill and Karutapallaiyam in the Coimbatore district. According to Mr. Middlemiss[2] the dysluite generally occurs in irregular masses or veinlets, but sometimes shows an attempt at the regular spinel form, namely the octahedron. The mineral was determined by H. H. Hayden, to whom it was forwarded from the field, the particular locality for the dysluite thus determined being $1\frac{1}{2}$ miles S.S.E. of Padiyur. Mr. Hayden reported the mineral to be a zinc-iron-

[1] O. A. Derby, *Amer. Jour. Sci.*, XII, p. 21, (1901).
[2] Manuscript notes.

manganese gahnite, the ratio of iron to alumina being 55 : 47. Besides iron and alumina it was found to contain a good deal of zinc and rather less manganese than zinc, with a trace of lime and magnesia, and a very little silica. The specific gravity was found to be 3·95—4·17.

The specimens collected by Mr. Middlemiss show masses of the dysluite up to 5 inches in length. They are very irregular in shape, sometimes shewing a tendency to the octahedral form characteristic of spinels. The immediately associated minerals are white and pink felspar, and biotite. The dysluite itself is black, breaking with a subconchoidal fracture, which when fresh shows a somewhat resinous lustre. The mineral scratches quartz. It is very difficult, however, to obtain a reaction for manganese in the ordinary way by fusion with nitre and fusion mixture. The result of two such tests was to lead to the supposition that manganese was not present. On first fusing the mineral with acid potassium sulphate and then adding nitre and fusion mixture a decided manganese reaction was, however, obtained. The streak of the mineral is a somewhat darkish grey.

Manganmagnetite.

As its name implies manganmagnetite is a variety of magnetite containing manganese. Three localities have been so far recorded for this variety. They are :—

Locality.	Contains :—	G.
Vester Silfberg, Sweden[1] . .	3·80 and 6·27% MnO . .	5·064
New Zealand[2] . . .	4·63% Mn_2O_3 and 7·15% MgO	4·67
Kodur, Vizagapatam, Madras[3] .	3·00% Mn_3O_4, 2·52% Al_2O_3	5·045

There seems to be some doubt as to which portion of the magnetite molecule contains the manganese. Thus the general formula of manganmagnetite may be expressed as $(Fe,Mn)O.(Fe,Mn)_3O_4$; or, if allowance be made for the magnesia shown in the New Zealand specimen and the alumina shown in the Kodur specimen, the formula may be stated as follows :—$(Fe,Mn,Mg)O.(Fe,Mn,Al)_3O_4$. And, if the presence of the alumina be neglected, manganmagnetite may be looked upon as providing the connecting link between magnetite and jacobsite. The Indian

[1] Mats Weibull, *Min. u. petr. Mittheil.*, VII, p. 109, (1886).
[2] A. H. Chester, *Min. Mag.*, VIII, p. 125, (1889).
[3] T. H. Holland, *Rec. Geol. Sur. Ind.*, XXVI, p. 165, (1893).

specimen investigated by Dr. Holland was strongly magnetic, showing distinct polarity, and otherwise exhibiting the properties of magnetite, except that its streak was reddish brown instead of black.

Occurrence.

In my examination of the manganese-ore deposits of the Vizagapatam district I found that what was apparently manganmagnetite is not at all uncommon. The difficulty is to avoid confounding it with braunite, for, as is explained on another page (63), this mineral is also magnetic, although to a much smaller degree. Both minerals have a lustrous black conchoidal to sub-conchoidal fracture, but braunite usually exhibits a well-marked octahedral cleavage not shown by manganmagnetite. When in small grains, however, the cleavage of the braunite may be difficult to develop. In this case if the mineral be not strongly magnetic it may be taken to be braunite, but it is best to confirm this deduction as to the character of the mineral by making a chemical test. The best is to treat the finely powdered mineral with strong hydrochloric acid. If the mineral be braunite it will leave a residue of gelatinous silica: whilst if it be manganmagnetite it will either dissolve completely, or it will leave only a very small residue due to mechanically included silica, which will not be gelatinous. If the mineral contain only a small amount of manganese, this will of course show that it is not braunite; but the presence of a large amount of manganese does not necessarily mean that the mineral is braunite, for there is another magnetic mineral, vredenburgite, that contains a high percentage of this element. The deposit at which I found manganmagnetite in the greatest abundance is Garbhám, but I also found it at Kodur and Ávagudem. At Garbhám it occurs in two ways. One is in a rock composed of manganese-garnet (spandite) with some apatite and a little mica (rich brown), in which the manganmagnetite forms perhaps one-third of the rock. The grains of manganmagnetite are $\frac{1}{6}$ to $\frac{1}{4}$ inch in diameter. When freshly fractured they are seen to be traversed by rather numerous thin veinlets of psilomelane. To test if the mineral were really manganmagnetite, containing the manganese in combination as a part of the molecule, was therefore a matter of some difficulty. After a lot of trouble some pieces were picked out that had fresh fracture surfaces on every side and showed no trace of the psilomelane veinlets. These were found to give decided reactions for manganese indicating its presence in appreciable quantity, but not in large amount. I must confess that I do not feel absolutely certain that any of the pieces tested were really quite free from psilomelane

veinlets, although as far as I could determine, by careful examination of the specimens to be tested under the microscope, they seemed quite pure. The manganese-ore quarried at Garbhám is frequently seen to contain scattered shining specks which at first sight one takes to be braunite. Judging, however, from the magnetism test, these bright specks consist more often of manganmagnetite than of braunite at Garbhám, thus accounting for the high percentage of iron found in these ores.

At Ávagudem a rather common form of ore is one composed of a mixture of psilomelane and pyrolusite with abundant scattered specks of a very magnetic mineral. As at Garbhám this magnetic mineral is traversed by veinlets of psilomelane, but to a still greater extent. With the greatest difficulty a piece was picked out which seemed to be free from these veinlets; this gave only a very weak reaction indicating not much more than a trace of manganese. At Kodur the patches and specks of the shining mineral that is so often seen in the manganese-ores are found to consist more often than not of braunite; but sometimes manganmagnetite traversed by psilomelane veinlets is found.

Origin.

As regards the origin of this manganmagnetite it is obvious that when it forms a part of the manganese-ores—which, as is explained on pages 262 to 272, are of secondary origin formed by the chemical alteration, with solution and re-deposition, of various constituents of the rocks of the kodurite series—it must also have been formed during the series of chemical changes by which the ores were formed. In the case of the spandite-rock at Garbhám in which it occurs it seems, however, possible that it may be an original mineral formed at the same time as the enclosing rock. Microscopic examination does not definitely settle this question. Under the microscope it is seen that the garnet is undoubtedly being replaced by manganese-ore (psilomelane). In places in the rock there are curious rims or borders of garnet to the opaque minerals consisting of manganmagnetite and psilomelane. Reflected light shows that on one side of the rim is manganmagnetite (grey-black), and on the other psilomelane (dull black) evidently replacing the garnet. The manganmagnetite does not show this evident replacement; hence it seems possible that the original rock was composed mainly of spandite and manganmagnetite and that manganiferous solutions have attacked the rock and replaced the garnet, in some places completely and in some cases only partially, so as to leave an unaltered rim of garnet between the manganmagnetite and the secondarily formed manganese-ore; whilst the manganmagnetite has escaped alteration,

except perhaps along the psilomelane veinlets that often traverse it in all directions. It is not certain, however, that the manganmagnetite is original as here supposed, although this hypothesis seems to suit the evidence.

In other parts of India manganmagnetite has not been commonly found. Probably, however, in most of the magnetite-bearing gneisses at Kándri and Mansar, Nágpur district, the supposed magnetite is manganiferous, being usually manganmagnetite, but possibly in some cases braunite.

Hausmannite.

Up to date no undoubted specimen of hausmannite has been found in India. It is true that Mr. R. B. Foote[1] says that the manganese-ore of Rámandrug in the Sandur Hills probably contains its manganese in the form of braunite or hausmannite. But the analysis quoted is sufficient to disprove this ; for the amount of oxygen found is much in excess of that required for either mineral. The specimens collected by Foote are apparently nodules of very impure psilomelane. Several selected specimens of manganese-ores from the Central Provinces were analysed at the Imperial Institute, London ; sometimes the specimens so analysed were found to be simple in composition and composed of one mineral only, but at other times they were found to be mixtures of two or more minerals. In calculating these latter analyses to their mineral composition it was sometimes found that the analysis might be taken as indicating the presence of a certain proportion of hausmannite. Thus alternative arrangements of the analyses of specimens Nos. 995 (Kándri) and 1037 (Mansar) given on pages 868 and 887 are the following :—

	Specimen No. 995. (Kándri.)	*Specimen No. 1037.* (Mansar.)
Apatite	0·35	0·49
Calcite	0·14	0·14
Braunite ($3Mn_2O_3.MnSiO_3$)	61·85	56·02
Psilomelane (including Fe)	16·21	22·94
Hausmannite	19·74	20·39
Quartz	1·64	0·36
As_2O_5	0·019	0·017
Moisture	0·15	0·10
	100·099	100·457
Oxygen assumed	0·07	..
Oxygen surplus	..	0·30
	100·029	100·757

[1] *Mem. Geol. Sur. Ind.*, XXV, p. 195, (1895).

The specimens, however, only indicated the presence of two minerals, one of them occurring in small crystalline grains set in a dull matrix of the other (psilomelane). Some of the crystalline grains might have been braunite and some hausmannite; but as the ore was similar to many other specimens in which calculation did not indicate the presence of hausmannite, it seemed likely that in these two cases also it was not present. This difficulty was surmounted by assuming that the ferric oxide, included in the psilomelane above as ferric manganate, replaced a part of the Mn_2O_3 of the braunite. It was found possible to take the Mn_2O_3 thus set free into the psilomelane together with the manganese oxide previously calculated as hausmannite; and thus the mineral composition was expressed in the terms of two minerals only (neglecting, of course, the traces of quartz, apatite, etc.) as shown on pages 869 and 888. These considerations have nevertheless been introduced here to show the possibility that some of the Central Provinces manganese-ores may contain hausmannite, although it has not been yet found possible to prove this in any particular case.

Vredenburgite.

In two different parts of India, namely Beldongri in the Nágpur district, Central Provinces, and Garividi in the Vizagapatam district, Madras, I have found a mineral that everything agrees in showing is a new species. In colour the mineral is a dark steel-grey exhibiting a bronze tint, especially in the sun. In fact it was this bronzy colour that first drew my attention to the mineral at Beldongri: the difference in tint between this and the ordinary manganese-ore of the mine was most marked, the latter, composed of a mixture of braunite and psilomelane, being of a dark steel-grey to black colour, with sometimes a tinge of bluish. The lustre of the mineral is metallic, but not very bright, except on cleavage surfaces. The Garividi specimen shows well-marked cleavage, the nature of which is not obvious, but which I would suggest is parallel either to the isometric octahedron or to the tetragonal pyramid, according to whether the mineral is isometric or tetragonal; for it will probably be found to belong to one of these two systems if specimens be ever found showing recognizable faces. The streak of the mineral is a deep brownish black tending to a deep

Characters and occurrence.

chocolate. Its hardness is about 6·5. The most interesting feature of the mineral, however, is its magnetism, for it seems to be just as strongly magnetic as ordinary magnetite ; and indeed, any one picking up a piece of it and testing it with a magnet would say at once that it was magnetite. That this would be incorrect is shown by the fact that the mineral contains a high percentage of manganese ; in fact, about twice as much of this element as of iron. The mineral is, moreover, distinctly polar, and pieces can be broken off, one end of which will attract one pole of a balanced magnetic needle and repel the other. The coarsely crystallized Garividi specimen is more suitable for this test than the more finely crystalline ore from Beldongri, the latter being of the nature of an aggregate in which the polarity of one individual may neutralize that of another.

The Beldongri specimen was found as a thin band, one inch in thickness, intercalated with the other ores in the south-east corner of the quarry, at the point D in Plate 37. This ore is moderately coarsely crystalline, as compared with the usual manganese-ores of this part of India, the individual grains averaging $\frac{1}{16}$ to $\frac{1}{4}$ inch across. This crystalline aggregate is very compact, and in parts the magnetic mineral tends to get mixed with a little psilomelane. A piece, apparently free from this latter impurity and having a specific gravity of 4·74, was selected for analysis, the latter being carried out at the Imperial Institute. The other specimen was obtained from amongst the heaps of ore from the Garividi deposit, stacked ready for despatch at the station of the same name. In contrast to the Beldongri specimen this is very coarsely crystalline, a piece about three inches in length consisting of only three individuals interlocking one with the other in a sort of poikilitic way. One of these individuals is two inches long. The Garividi specimen, moreover, does not contain any other admixed mineral. The piece of it chosen for analysis had a specific gravity of 4·84, which is somewhat higher than that of the Beldongri specimen. This may mean that there was a little admixed psilomelane in the Beldongri ore, although the way in which the analysis works out to a definite formula does not support this supposition. The slight differences in specific gravity may be due to slight differences in the impurities that each of the specimens probably contain (see the analyses on the next three pages). The Garividi specimen was analysed by Messrs. J. & H. S. Pattinson of Newcastle-on-Tyne.

Chemical composition.

The two analyses are given side by side below :—

	Specimen No. 1080. (Beldongri.)	*Specimen No. A. 346.* (Garividi.)
Manganese peroxide (MnO_2)	23·67	24·94
Manganese protoxide (MnO)	38·24	38·53
Ferric oxide (Fe_2O_3)	28·85	31·29
Alumina (Al_2O_3)	1·32	2·10
Baryta (BaO)	1·30	0·03
Lime (CaO)	1·53	0·90
Magnesia (MgO)	0·99	1·20
Potash (K_2O)	..	0·06
Soda (Na_2O)	..	0·14
Combined silica (SiO_2)	0·91	0·20
Free silica (SiO_2)	0·86	*Nil*
Sulphur	..	0·03
Phosphoric oxide (P_2O_5)	1·07	0·03
Arsenic oxide (As_2O_5)	0·01	*Nil*
Cobaltous oxide (CoO)	..	0·05
Nickelous oxide (NiO)	..	*Nil*
Cupric oxide (CuO)	..	0·03
Lead oxide (PbO)	..	*Nil*
Zinc oxide (ZnO)	..	*Nil*
Titanic oxide (TiO_2)	..	0·14
Chlorine and fluorine	..	*Nil*
Combined water	1·32	0·30
Moisture at 100°C	0·18	0·20
Carbon dioxide (CO_2)	0·09	*Nil*
	100·34	100·17
Manganese	44·62	45·62
Iron	20·19	21·90
Silica (total)	1·77	0·20
Phosphorus	0·47	0·02
Specific gravity	4·74	4·84

It is evident from the foregoing analyses that these two specimens represent one and the same mineral composed practically entirely of oxides of manganese and iron; all the other constituents being present in insignificant proportions may be regarded as impurities. The question is then to calculate from these two analyses the formula of the mineral.

I will first consider the mineralogical composition of the Beldongri specimen. If the combined silica shown in the analysis be really in this

condition then it will probably be as braunite. On this assumption the analysis can be re-stated as follows :—

Apatite	2·47
Calcite	0·20
Braunite	9·12
Hausmannite	53·82
Hematite	28·85
Impurities—	
Alumina	1·32
Baryta	1·30
Lime	0·02
Magnesia	0·99
Combined water	1·32
Quartz	0·86
Arsenic oxide	0·01
Moisture	0·18
	100·46
Subtract oxygen assumed	0·12
	100·34

On the supposition that the combined silica is present as braunite there is no alternative to the above interpretation of the analysis ; for the Mn_3O_4 and Fe_2O_3 are not then present in any simple molecular proportion. But in accordance with this interpretation there should be three constituents easily visible in the hand-specimen, namely braunite, hausmannite, and hematite. Examination of the specimen, however, does not reveal the presence of more than one constituent. If, on the other hand, we assume that the combined silica is in combination with some of the impurities, then the analysis can be stated as follows :—

Apatite	2·47
Calcite	0·20
Mn_3O_4	61·93
Fe_2O_3	28·85
Impurities	5·86
Quartz	0·86
As_2O_5	0·01
Moisture	0·18
	100·36
Subtract oxygen assumed	0·02
	100·34

Now the Mn_3O_4 and Fe_2O_3 are present in the molecular proportions of 3 to 2 as shown below :—

$$\frac{61{\cdot}93}{229} = {\cdot}2704 = 3 \times {\cdot}09013$$

$$\frac{28{\cdot}85}{160} = {\cdot}1803 = 2 \times {\cdot}09015$$

Hence we can suppose that they form a mineral of the composition $3Mn_3O_4.2Fe_2O_3$, rather than a mixture of hausmannite and hematite.

Taking now the case of the Garividi analysis, all the constituents may be regarded as impurities accidentally picked up during the formation of the mineral, except the oxides of manganese and iron, to which, as in the case of the Beldongri specimen, we will confine our attention. The oxides of manganese given in the analysis on page 44 correspond to :—

Manganese	45·61
Oxygen	17·86

Now 45·61 manganese requires 17·70 oxygen for the formation of Mn_3O_4, so that here also it seems almost certain that the manganese is present in the form of the proto-sesquioxide. Again the question arises as to whether this Mn_3O_4 is to be regarded as hausmannite in mechanical admixture with the Fe_2O_3 in the form of hematite, or whether the oxides of manganese and iron are in combination as some definite molecule with a definite molecular formula. Calculation shows that the relation between the Mn_3O_4 and the Fe_2O_3 is not so exact as in the case of the Beldongri specimen. Neglecting all the constituents except the oxides of manganese and iron the composition of the mineral is :—

Mn_3O_4	63·31
Fe_2O_3	31·29
Surplus oxygen . . .	0·16
	94·76

Now to satisfy the formula $3Mn_3O_4.2Fe_2O_3$, 63·31 Mn_3O_4 requires 29·49 Fe_2O_3, whilst 31·29 is available; that is, there is a surplus of 1·80 Fe_2O_3. This is not excessive and may be taken as showing that the Garividi specimen has the same formula as the Beldongri

specimen, the extra Fe_2O_3 being regarded as a further portion of the impurities.

On the evidence of the foregoing calculations it might then be considered as fairly certain that the formula of this mineral is really $3Mn_3O_4.2Fe_2O_3$. At first sight, however, there might seem to be an objection to this formula in the fact that the mineral is so strongly magnetic that the iron must be supposed to be present as Fe_3O_4 rather than as Fe_2O_3. But this is not a real objection, because there are several minerals exhibiting magnetic properties—usually it is true, to a much smaller degree than magnetite—that do not contain their iron in the form of Fe_3O_4. Thus pyrrhotite or magnetic pyrites, a sulphide of the formula $Fe_{11}S_{12}$, is often strongly magnetic. Ilmenite is often slightly magnetic. Its formula may be written either as $FeTiO_3$, as $(Fe,Ti)_2O_3$, or as $mFeTiO_3.nFe_2O_3$. Whichever interpretation be the correct it is seen that the iron is in the form of either FeO or Fe_2O_3. Since hematite (Fe_2O_3) is usually non-magnetic, it seems as if the magnetism of ilmenite must be due to the presence in it of titanium and not iron. In the same way all the Indian braunites are more or less magnetic. Although the formula of braunite is open to some doubt, as is shown in the section dealing with this mineral, yet no interpretation of it shows the presence of an R_3O_4 group. Now the Indian braunites usually contain an appreciable proportion of iron replacing a part of the manganese. Such iron must, therefore, be in the form either of Fe_2O_3 or, less likely, of FeO. It so happens, however, that some braunites are very low in their iron percentage, and yet are still magnetic. Hence we must suppose that, as in the case of the ilmenite the magnetic properties of the mineral are due to the titanium rather than to the iron, so in the case of braunite the magnetism is due to the manganese rather than to the iron. Hence in the case of the mineral under consideration it does not necessarily follow that its magnetic properties are due to the iron, even though it is present in large amount. The manganese may be the cause of the magnetism; but considering the strength of this property it seems more probable that the iron has something to do with the magnetism. It may be that this particular proportion of manganese and iron oxides gives rise to the magnetism. It will be seen from the foregoing that even if the magnetism be entirely due to the presence of the iron, it does not follow that it is present in the form of Fe_3O_4. It will be interesting, however, to see if the analysis can be interpreted on the supposition that the iron is present in the Fe_3O_4 condition.

If in each of the analyses the iron be supposed to be present in the form of Fe_3O_4 and the manganese in the form of Mn_2O_3, then the amounts of these oxides work out as follows :—

	Beldongri.	Garividi.
Mn_2O_3	64·08	65·51
Fe_3O_4	27·89	30·25
	91·97	95·76
Subtract O assumed . .	1·21	1·00
	90·76	94·76

With this arrangement the formula works out as corresponding in both cases very closely to $10Mn_2O_3.3Fe_3O_4$. Since, however, the error in the oxygen is on this interpretation so large, it would be better to suppose that the manganese is not all in the form of Mn_2O_3, but that a portion of it is in the R_3O_4 group isomorphously replacing a portion of the iron. On this supposition and using the oxygen, manganese, and iron, as actually determined, as the basis of calculation, the composition works out as follows :—

	Beldongri.	Garividi.
Mn_2O_3	28·23	35·89
Mn_3O_4	34·64	28·62
Fe_3O_4	27·89	30·25
	90·76	94·76

The molecular proportions of the three oxides then work out as follows :—

Beldongri.

Mn_2O_3	= ·1787		= 2 × ·0893
Mn_3O_4	= ·1513	·2715	= 3 × ·0905
Fe_3O_4	= ·1202		

Garividi.

Mn_2O_3	= ·2271		= 7 × ·0324
Mn_3O_4	= ·1249	·2553	= 8 × ·0319
Fe_3O_4	= ·1304		

These correspond respectively to the formulæ—

Beldongri . . .	$2Mn_2O_3.3(Mn,Fe)_3O_4$
Garividi . . .	$7Mn_2O_3.8(Mn,Fe)_3O_4$

We have thus arrived at the following alternative formulæ :—

Beldongri.	Garividi.
$3Mn_3O_4.2Fe_2O_3$	$3Mn_3O_4.2Fe_2O_3$
$10Mn_2O_3.3Fe_3O_4$	$10Mn_2O_3.3Fe_3O_4$
$2Mn_2O_3.3(Mn,Fe)_3O_4$	$7Mn_2O_3.8(Mn,Fe)_3O_4$

Of these formulæ the simplest is the first, to which the analyses correspond more nearly than to any other, if a little of the iron be regarded as impurity in the Garividi specimen. The second is the least probable interpretation as it is then necessary to assume errors of 1·00 and 1·21, respectively, in the determination of the oxygen. Whichever be the correct formula there is no doubt that this mineral is a new mineral species. I propose to call it *vredenburgite* after my colleague Mr. E. W. Vredenburg, under whom I spent my first field season in India and first came in contact with deposits of manganese-ore. Its main interest lies in its combination of strongly magnetic characters with a high percentage of manganese. In consequence of the former property it is liable to be mistaken for magnetite if—as is only natural, considering that up to the present the only black strongly magnetic mineral[1] that has been recognised is magnetite—its chemical character be not determined. Whilst on account of its well-marked cleavage and the fact that it is found in manganese deposits, it is liable to be mistaken for braunite, unless its magnetic characters be examined. The fact that it dissolves up practically completely in acid, without leaving a residue of silica, serves to distinguish it from braunite; so also does its duller lustre on cleavage surfaces and its curious bronzy lustre in the sun. Otherwise, in hardness, cleavage, and specific gravity, there is a remarkable similarity between these two minerals

Sitaparite.

At Sitapár in the Chhindwára district, Central Provinces, there occurs amongst the interesting association of minerals forming the ores of this place a dark bronze-coloured mineral that looks very like the one I have called vredenburgite. It is, however, distinguished from the latter by the fact that it is only slightly magnetic, vredenburgite being about as magnetic as magnetite. The actual colour of the mineral may be described as dark bronze-grey, the bronze tint being especially well seen in the sun. It is, moreover, sufficiently well marked for the mineral to be at once distinguished from its associates in the ores in which it occurs. The streak is black, the lustre metallic. The mineral is brittle and tends to break along almost perfect cleavage planes, which may be octahedral. The hardness of the mineral is about the same as that of quartz. The specific gravity seems to be somewhat variable, three pieces showing

Characters.

[1] Excluding native elements.

values for this constant of 4·93, 4·99, and 5·09, the mean value being 5·00. An analysis of this mineral was made by Mr. T. R. Blyth, of the Geological Survey of India, on a piece having a specific gravity of 4·93. The result is as follows :—

Chemical composition.

Specimen No. 843 A.

Manganese peroxide	36·79
Manganese protoxide	26·89
Ferric oxide	27·60
Alumina	1·02
Baryta	0·10
Lime	6·14
Magnesia	1·02
Silica	1·17
Moisture at 100° C.	0·09
	100·82
Manganese	44·09
Iron	19·32
Specific gravity	4·93

Below are compared the figures for the oxides of manganese and iron, and metallic manganese and iron, with those for the two specimens of vredenburgite of which the full analyses are given on page 44 :—

	Beldongri.	Garividi.	Sitapár.
MnO_2	23·67	24·94	36·79
MnO	38·24	38·53	26·89
Fe_2O_3	28·85	31·29	27·60
	90·76	94·76	91·28
Manganese	44·62	45·62	44·09
Iron	20·19	21·90	19·32

It will be seen that there is a striking resemblance between the Sitapár mineral and the two specimens of vredenburgite, particularly in the amounts of ferric oxide, manganese, and iron. The difference between the two minerals lies, however, in the state of oxidation of the manganese. Whilst vredenburgite contains considerably more MnO than MnO_2, the relative amounts of these two oxides are reversed in the Sitapár mineral. Consequently the Sitapár mineral cannot be made to conform to the formula of vredenburgite. In the case of vredenburgite I regarded the constituents other than the above as impurities, because none of them was present in any important quantity, nor had

any important effect on the formula. Their total amount was, however, not so small, being about 9 per cent. in the Beldongri specimen and 5 per cent. in the Garividi specimen.

In the present case one of the constituents other than oxides of manganese and iron is present in sufficient quantity for it to be necessary to take it into account in calculating the formula. This is the lime; and in investigating the significance of this constituent in the formula I have grouped with it the oxides of barium and magnesium. Below I give the figures for the molecular ratio of each constituent:—

$$MnO_2 = \frac{36{\cdot}79}{87} = 0{\cdot}4230 = 10 \times {\cdot}0422$$

$$MnO = \frac{26{\cdot}89}{71} = 0{\cdot}3787 = 9 \times {\cdot}0421$$

$$Fe_2O_3 = \frac{27{\cdot}60}{160} = 0{\cdot}1725 = 4 \times {\cdot}0431$$

$$CaO = \frac{6{\cdot}14}{56} = 0{\cdot}1096$$

$$MgO = \frac{1{\cdot}02}{40{\cdot}36} = 0{\cdot}0253 \quad \Big\} = 0{\cdot}1355 = 3 \times {\cdot}0452$$

$$BaO = \frac{0{\cdot}10}{153{\cdot}4} = 0{\cdot}0006$$

$$SiO_2 = \frac{1{\cdot}17}{60{\cdot}4} = 0{\cdot}0194 = \tfrac{2}{5} \times {\cdot}0485$$

In the last line I have also given the molecular ratio for the silica to show that it is present in too small a quantity to be taken into account in working out the formula of the mineral. It will be seen, however, that the CaO, MgO and BaO taken together are molecularly nearly as important as the ferric oxide. According to the above the formula is as follows:—

$$10MnO_2.9MnO.4Fe_2O_3.3(Ca,Mg,Ba)O.$$

Leaving out the MgO and BaO and grouping together the oxides of manganese this can be stated more simply as follows:—

$$9Mn_2O_3.4Fe_2O_3.MnO_2.3CaO.$$

From this it might be thought that the mineral is only to be regarded as a variety of the very rare sort of braunite having the simple formula Mn_2O_3, in which a portion of the manganese is replaced by iron, the one molecule of MnO_2 and the 3 of CaO being impurities. The quantity of the latter seems to me to be too large for it to be treated as an impurity, especially as the specimen analysed was a portion of one crystal only and was apparently quite pure and free from adventitious matter. Apart from the presence of the lime and excess MnO_2, the bronze tint of the mineral is sufficient to show that the mineral is not a variety of any sort of braunite ; for the latter usually possesses a rich black colour, and is, moreover, present in the same ore, as a mineral of very different appearance. Another alternative is to regard the iron as being present in the form of Fe_3O_4. Under this supposition the formula of the mineral works out as $6Mn_3O_4.4Fe_3O_4.12MnO_2.5CaO$. It does not, even in this form, show any close relationship in formula to any other mineral. Hence it seems better to accept the simpler formula $9Mn_2O_3,4Fe_2O_3.MnO_2.3CaO$, as the best expression of the composition of this mineral, and to regard it as a new species. As the locality where it is found contains such a number of interesting minerals I think this mineral can be most appropriately called *sitaparite*.[1] I do not at present know what is the meaning of the variable specific gravity noted above. It may correspond to a variation in the composition of the mineral in which one constituent is replaced by another without altering the general formula of the mineral. Further work on the mineral, when a larger number of specimens have been analysed, may result in a modification of the formula of the mineral as given above, but it will not alter the fact that the mineral has a individuality that enables it to be distinguished from all other manganese minerals. The only two minerals to which it bears any resemblance are manganmagnetite and vredenburgite. It is distinguished from the former by its bronze tint and weak magnetism ; and from the latter, which it resembles in its bronze tint, by its weak magnetism.

Braunite.

Of all the manganese-ores found in India braunite is, with the exception of psilomelane, the most important. The existence of this

1 To be pronounced with the accent on the third syllable in which the 'a' is like the 'a' in 'park'. The 'i' in 'Sita' is pronounced like 'ee'.

mineral in India was first recognized by Dr. A. J. Scott in 1852[1], who analysed two specimens said to have come from Vizianagram and Bimlipatam, respectively. As manganese-ores are not known to exist at either of these towns, the probability is that the specimens were obtained from the manganiferous area of the district in which these two places are situated. From the account given of the characters of the ores examined it is evident that they consisted of mixtures of braunite and psilomelane. The analyses of these two specimens are given in the paper cited, and Scott remarks with regard to the Vizianagram ore that its analysis agrees most nearly with that of Damour's Marcellin, an impure braunite from St. Marcel in Piedmont. Two years later Mr. Marcadieu recorded the discovery near Dharmsála in the Punjab (see page 1156) of a mineral that 'approaches by its composition and crystalline form to marcelline'. The crystals he describes as octahedral with a square basis.[2] Since then it has been found to occur in great abundance in various parts of India. I do not intend to give here a detailed account of all the occurrences of this ore, but will only refer to the most interesting and important of them. An account of all that was known about Indian braunite up to the year 1887 will, however, be found on pages 55 to 57 of Mallet's 'Mineralogy'.

Occurrence.

As far as my own experience goes braunite is found in India only in association with the manganese-ore deposits that occur in the Archæan rocks. And, as is described in the chapters dealing with the geology of these deposits, there are two chief groups of these deposits. The braunite that occurs in the deposits formed by the chemical alteration of the rocks of the kodurite series in Vizagapatam has, if my view of the origin of the ores of this area be correct, been formed during the chemical changes by which the manganese-ores were derived from the manganese-silicate minerals. In these deposits, however, braunite is not nearly so abundant as in the deposits occurring in the rocks of Dhárwár age in the Central Provinces, Central India, and Nárukot, *i.e.*, in association with the gondite series. In these latter deposits I suppose that a portion of the manganese-ores has been formed direct by the metamorphism of the original manganiferous sediments, whilst another portion of the ores has been formed by the chemical alteration of the manganese silicates that were formed by the metamorphism of the more impure of the

[1] *Edin. New Phil. Jour.*, LIII, pp. 277-279.
[2] Selections, Public Correspondence, Punjab Administration, II, No. vii, p. 4.

original manganiferous sediments. It is probable, as far as can be judged from the careful study of the specimens collected, that braunite, which is often the predominant mineral in these deposits, has been formed in both ways. At one locality in the Central Provinces, namely Kácharwáhi in the Nágpur district, braunite crystals are found in abundance in an albite-rock that is probably intrusive in the ore-body. Hence we see that the Indian braunite has been formed in three distinct ways, as follows :—

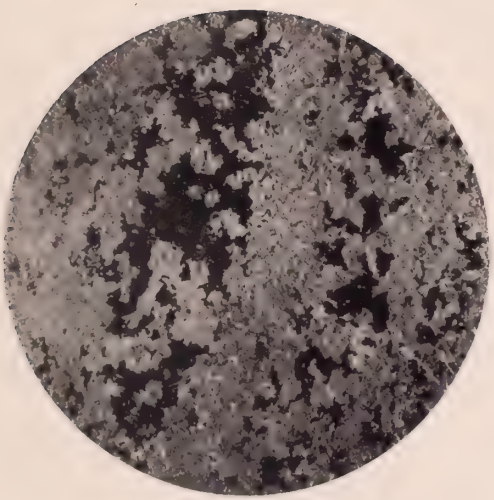
1. By crystallization from an igneous intrusive ; at Kácharwáhi.

2. By the metamorphism of manganiferous sediments ; in the Central Provinces, Central India (Jhábua), and Nárukot.

3. During the chemical alteration under the influence of waters—probably heated, and containing chemical reagents and solvents—of manganese silicates, such as manganese garnets and manganese-pyroxenes, these silicates being contained (*a*) in the igneous rocks of the kodurite series in Vizagapatam, and (*b*) in the metamorphic rocks of the gondite series in the Central Provinces, Central India, and possibly Nárukot.

There is no certain evidence of the occurrence of this mineral in any other areas in India, or in rocks of any other age, than those mentioned above. It must be mentioned, however, that minute specks of a crystalline mineral sometimes showing octahedral faces are occasionally seen sparsely distributed in the ores of other areas, especially the Sandur Hills. This mineral may also be braunite, but has not been investigated, and is perhaps more likely to be magnetite.

In view of the enormous quantities of this mineral that exist in India it might be thought that abundance of material would now be available for the convenient study of the crystallographic characters of this mineral. Such, however, is not the case, the mineral being only rarely found in measurable crystals. In the Vizagapatam deposits it usually occurs as specks and patches of irregular shape embedded in a matrix of psilomelane. In fact I have not obtained from this area a single specimen showing crystal faces. In the deposits of the Central Provinces, Jhábua, and Nárukot, the mineral usually occurs in one of two forms. One of these is a finely granular aggregate in which all the grains are braunite pressed one against the other, but showing a tendency to a general octahedral shape. The other is a rock composed of a mixture of braunite and psilomelane, little granules of the braunite being set in a matrix of psilomelane. (Plate I shows a photomicrograph of a polished and etched slice of such ore.) The proportions



L. L. Fermor, Photomicrograph. *Bemrose, Collo., Derby.*

× 16.

Photomicrograph by reflected light of a polished and etched slice of manganese-ore from Rámdongri, Nágpur district, C. P.

The dark part is braunite (crystalline), and the light part, or matrix in which the braunite is set, is psilomelane.

between the two are subject to great variation, and such ore can grade into psilomelane on the one hand and into the granular aggregate of braunite mentioned above on the other hand. In this mixture the braunite individuals sometimes become quite large, as much as ½ to 1 inch across; but even then the development of crystal faces is prevented by the cement of psilomelane, or by the braunite crystals either interlocking with or pressing against one another. In one case, namely at Lohdongri in the Nágpur district, there are spaces between the layers of ore in which the braunite has had the opportunity of developing crystal faces (for an account of the exact mode of occurrence see page 917); whilst at Kájlidongri also, crystals with well developed faces have been obtained by Mr. H. J. Winch, presumably from some cavity in the ore; a single specimen was also obtained by the late Mr. A. M. Gow Smith at Kodegáon in the Nágpur district. The best locality for crystals is, however, Kácharwáhi, where they are to be found in abundance in an albite-rock, frequently containing blanfordite and sometimes quartz, and which as mentioned above is intrusive in the ore-body. One individual showing crystal faces was also noticed amongst the ores from Sitapár. The total number of specimens from these five localities is considerable, as also is the number of faces represented.

Crystallographic characters: value of the fundamental angle pp'.

I have not yet been able to carry out a detailed crystallographic investigation of all the forms represented, so that I do not propose to give here details of the angular measurements made up to date. The angle pp' between the faces of the unit pyramid was measured on a considerable number of crystals. For this purpose the crystals from Kájlidongri were found to be the best fitted, since they give the brightest reflections. The mean of the value for this angle determined over 12 edges measured on 6 crystals was found to be 70° 22′, the range in angles being from 70° 17′ to 70° 27½′. In the majority of the Kácharwáhi specimens the edges are rounded, with a corresponding corrosion of the faces, so that good reflections are difficult to obtain. Hence of a number of measurements made only 5 were considered to be worth taking into account. These were made on five edges distributed over four crystals. The values ranged from 70° 13½′ to 70° 25½′, the mean being 70° 18½′. Of the Lohdongri braunite only two suitable specimens were available. From these only one measurement was of any value, being 79° 25′. The Kodegáon and Sitapár specimens were not suitable for goniometric measurement. The mean of all the values given above is

70° 21′. Now the following values for this angle *pp′* have been determined by various observers :—

Author.	Locality.	Value.
Haidinger [1]	St. Marcel, Piedmont	70° 7′
Des Cloizeaux [2]	Ditto	70° 14′
Vom Rath [3]	Ditto	70° 8′ and 70° 13′
Flink [4]	Långban, Sweden	70° 19′

It will be seen that the mean of my determinations agrees with Flink's value rather than those of other observers ; and as the difference from that of Flink is only 2′, I shall accept his value for the present. I do not, however, think that the determinations of the other observers are to be regarded as incorrect ; indeed I think it probable that there is a small variation in the value of this angle from crystal to crystal, corresponding with the variation in composition to be noted later ; and probably the difference between the values of this angle on the Kájlidongri and Kácharwáhi braunites and on the foreign braunites is due to some difference between the composition of the crystals from the different places. It is further probable that even at one locality there is a variation from specimen to specimen. Thus of the crystals from Kájlidongri one gave the following four values for *pp′* :—70° 27′, 27½′, 26′, and 17′, the images for the first three angles being very good and one of those for the fourth edge poor ; whilst another crystal from the same mine gave the following values, of which the first three are from very good reflections :—70° 18′, 18½′, 18′, and 20½′. Hence it seems probable that the composition of these two specimens must be slightly different, corresponding to an angle of 70° 27′ in one case and 70° 18′ in the other.

Length of the vertical axis, $\dot{c}$.

From the value 70° 19′ Flink calculates the value of $\dot{c}$, the vertical crystallographic axis, to be 0·9924, in the paper cited above, and 0·99218 in a later paper.[5] From this value 70° 19′, however, I calculate the value to be 0·99220, giving the value for c^2, so useful in calculating the angles between the faces of the crystals, as 0·98447.

The habits of the crystals from the different localities vary consider-

[1] *Trans. Roy. Soc. Edinb.*, XI, pp. 132-134, (1831).
[2] *Annales des Mines*, 4mo. Ser., I, p. 423, (1842).
[3] *Sitzungsb. d. nied. Gesells. Bonn*, p. 224, Dec. 1882.
[4] *Bihang. k. Sv. Vet. Akad. Handl.*, XIII, Part II, No. 7, p. 37, (1888).
[5] *Op. cit.*, XVI, Part II, No. 4, p. 7, (1890).

The Kájlidongri crystals.

ably. Thus the prevailing form at Kájlidongri is the combination of the fundamental pyramid p or (111) with the ditetragonal pyramid x or (421), see fig. 1. Sometimes thin bevelling edges of r or (865) are present,

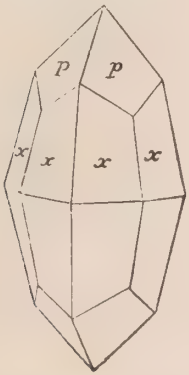


FIG. 1.—Braunite, Kájlidongri.

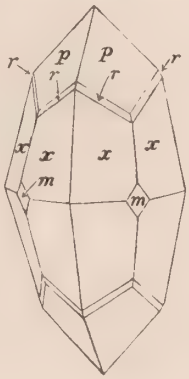


FIG. 2.—Braunite, Kájlidongri.

as in fig. 2, and very rarely little faces of the prism of the first order m or (110) shown in the same figure. Very rarely these crystals are truncated by the basal plane c or (001). Simple pyramids or octahedra are very rare and no twins have yet been observed.

The ácharwáhi crystals.

At Kácharwáhi, on the other hand, simple tetragonal pyramids or octahedra are common, although they often show the basal plane c as well, as in fig. 3. Frequently the octahedral crystals are rendered more complicated by the presence of faces of the ditetragonal pyramid y or (423), as shown in fig. 4.

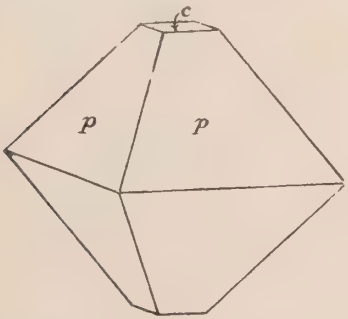


FIG. 3.—Braunite, Kácharwáhi.

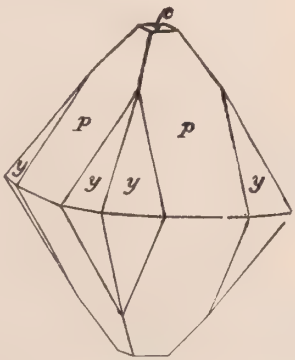


FIG. 4.—Braunite, Kácharwáhi.

The ditetragonal pyramid x is also fairly often present, one of its commonest combinations being with p, as in fig. 1; but as the angles are somewhat rounded these crystals tend to be barrel-shaped in aspect. Fig. 5 shows a combination of p, x, y, m, and c, this being the only example of the face m found on the crystals from this locality.

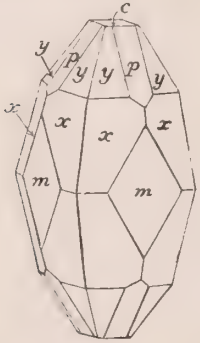


FIG. 5.—Braunite, Kácharwáhi.

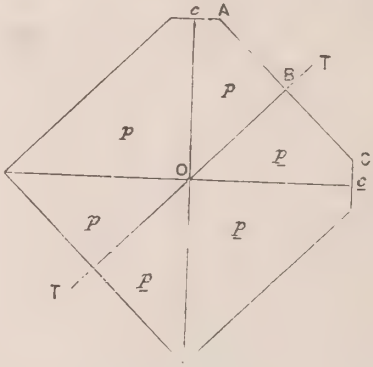


FIG. 6.—Braunite twin, Kácharwáhi.

Another crystal, which, if perfect, would be some 4 inches long, shows one face of r, in addition to the forms p and x shown in fig. 1. Besides these simple crystals, *twins* are very abundant in this deposit. One of the commonest is a simple *contact twin* on the plane e or (101), shown in fig. 6. Since the fundamental pyramid of braunite approaches very closely to the cubic octahedron, the edges AB and BC of fig. 6, instead of showing a

Twins.

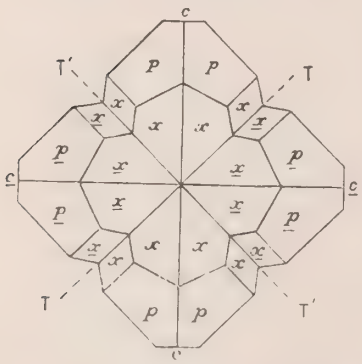


FIG. 7.—Braunite twin, Kácharwáhi.

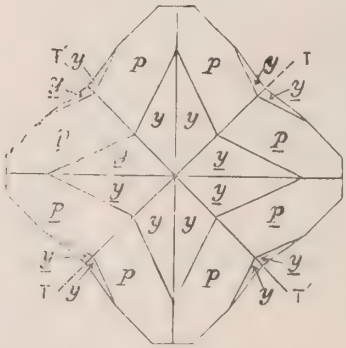


FIG. 8.—Braunite twin, Kácharwáhi.

re-entrant angle, seem to be in a perfectly straight line; whilst the two adjacent faces ABO and BCO are almost in the same plane, so that they seem to reflect light almost simultaneously, and, as viewed on the goniometer, give images that are only a few minutes distant from each other. Consequently, when the pyramid is not truncated by the basal plane in the way shown in fig. 6, the fact that the crystal is a twin is very apt to be overlooked. If, however, the crystal is cleaned its twinned nature is revealed by the existence on the apparently continuous plane AOC of the line BO. When the basal plane is present, the twinned character of the crystal is rendered obvious by the juxtaposition of the two planes c and $\underline{c}$. These contact twins also show the faces y modifying p. In addition to the contact twins, *interpenetration twins* are common. One of these, composed of c, p, and x, is shown in fig. 7, the presence of x giving rise to re-entrant angles. Interpenetration twins of the form c, p, and y, have also been found, as in fig. 8.

A new form.

One other habit that requires notice is that illustrated in fig. 9, in which the forms represented are p, x, y, and the new face g. The latter is, of course, a pyramid of the second order, steeper than the pyramid of the second order, e or (101), mentioned above as a twinning plane, but to be noticed below as a

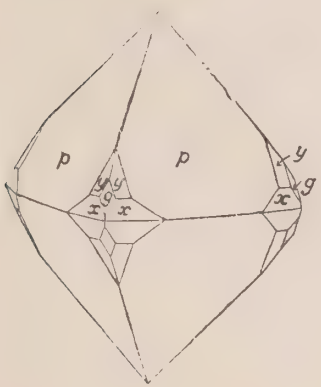


FIG. 9.—Braunite, Kácharwáhi.

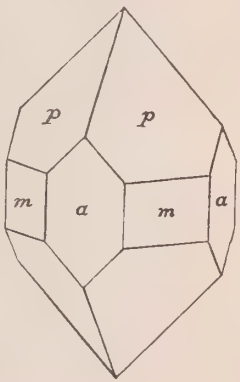


FIG. 10.—Braunite, Lohdongri.

face actually observed. The specimen from which this figure was drawn was a minute chip showing only one corner of the crystal with two p

faces, two y faces, one x face, and one g face. The formula of the face g is completely determined as (201) by the fact that it is situated in the two zones whose symbols are $[11\bar{2}]$ and $[\bar{1}12]$. The angular measurements confirm the symbol (201).

The Lohdongri crystals.

For the Lohdongri crystals I am mainly dependent on the notes I made when at Lohdongri, where Mr. E. L. Young has a fine set of specimens of braunite from this deposit. One of these, kindly lent to me by Mr. Young, is shown in Plate 2, from which it will be seen what a size the Indian braunite crystals sometimes attain. This specimen shows the simple octahedron or pyramid, p, one of which measures 3 inches along an edge between two pyramid faces ; one of the pyramids is truncated by c. Of some small crystals presented by Mr. W. H. Clark of Kámthi, three show the simple octahedron, whilst one is a contact twin on e, of the habit represented in fig. 1, the forms present being p and x. Of the specimens I examined at Lohdongri, one is represented in fig. 10, being a combination of p and m, with the prism of the second order, a or (100), which I have not seen on any other Indian specimen. Another crystal showed a combination of c, p, x, and the rare face e or (101), which, although commonly found as a twinning plane, is very rarely seen as a face on braunite crystals. Other crystals show combinations of c, p, and y, similar to fig. 4, but with c and y more prominently developed relatively to p. One octahedron was elongated along a horizontal axis bisecting the angle between the two lateral axes of braunite, so that the truncating basal plane was drawn out into a long rectangular face.

The Kodegáon crystal.

From Kodegáon only one crystal has been obtained. This is a fine specimen, which if whole would be some 2 to 3 inches across. It is of great interest on account of the faces shown, being a combination of p, y, and the rare form e, all well developed, with in addition a new form z.

A new form.

This is a ditetragonal pyramid that is less steep than e, and consequently forms the top end of the crystal. Only two faces are shown, and on account of the large size of the specimen, so that it cannot be accurately measured on the reflecting goniometer, and the fact that the new face cannot be referred to two intersecting zones, or even to one zone with two known faces, I have not yet been able to determine for certain what is the symbol of the face. It may be either (425) or (849) ; the measurements agree more closely with (425) than with the other form. As this form has not yet been certainly determined I have not figured it here.

Photo. by H. B. W. Garrick. *Calcutta Phototype Co.*

MASS OF BRAUNITE CRYSTALS FROM LOHDONGRI, NĀGPUR DISTRICT, C. P. $\frac{1}{3}$ NATURAL SIZE.

Three new forms.

From the above it will be seen that the Indian braunites have yielded three new forms, designated by the letters g, z, and r. The face g, or (201), found only on one Kácharwáhi specimen, I have already noticed. The face r is found quite commonly on the Kájlidongri specimens. Owing to the extreme narrowness of the edges representing this form, the images it gives are extremely faint and usually very blurred. Consequently it is not certain that it is always the same face that is present. The most likely one, however, seems to be that having the formula (865); sometimes, however, there is more than one of these faces between p and x; one of these others may then correspond to (976). One face in the same position has also been noticed on a specimen of Kácharwáhi braunite. This was too dull for measurement, but is probably the same as that found on the Kájlidongri mineral. The third new face z, of the probable formula (425), is noticed above.

Striations.

Some of the faces of the Indian braunite crystals often exhibit striations. The commonest are horizontal ones, sometimes taking the form of deep grooves, on the faces of x, parallel to the intersection of each face of this form with the corresponding face on the opposite side of the plane containing the lateral axes; for example, parallel to the intersection of 421 and $42\bar{1}$ More rarely the faces of the form y are striated parallel to their intersections with the faces of the form p. Thus 423 would be striated parallel to its intersection with 111, and $4\bar{2}3$ to its intersection with $1\bar{1}1$. Further, on the Kájlidongri specimens the pyramid faces, p, are often not perfectly plane, but marked with two sets of crossing striations parallel to the intersections of each p face with the two underlying x faces, the crystal being placed in the position shown in fig. 1.

Size of crystals.

In size the crystals of Kácharwáhi and Lohdongri range from a diameter of a small fraction of an inch, to 2, 3, or even 4, inches across. The one crystal from Kodegáon would be 2 to 3 inches in diameter if whole. The Kájlidongri crystals seldom reach such dimensions, being usually about $\frac{1}{8}$ to $\frac{1}{2}$ inch long; but some would be, if whole, 1 to $1\frac{1}{2}$ inches long. (Plate 2)

List of forms on Indian and foreign braunites.

From the foregoing it will be seen that 10 forms have been recognized on the Indian braunites. The following table shows their symbols, and distribution amongst the different localities :—

TABLE 5.

Faces observed on Indian braunites.

Forms.	Kájlidongri.	Káchar-wáhi.	Kodegáon.	Lohdongri.	Sitapár.
c or (001)	*c*	*c*	..	*c*	*c*
a or (100)	..	..	..	*a*	..
m or (110)	*m*	*m*	..	*m*	..
e[1] or (101)	...	as tw. pl.	*e*	*e* (and as tw. pl).	..
p or (111)	*p*	*p*	*p*	*p*	*p*
x[2] or (421)	*x*	*x*	..	*x*	..
y[3] or (423)	..	*y*	*y*	*y*	..
z or (425)?	..	..	*z*	..	..
g or (201)	..	*g*	..	..	..
r or (865)	*r*	*r*	..	..	..

Of the above, the first seven forms have also been found on foreign braunites. In addition the following five forms have been recorded by Flink [4] as occurring on the braunite of Långban :—

$o = (304)$; $l = (401)$; $i = (212)$; $s = (645)$; $t = (524)$;

whilst the form $s = (221)$, designated q by Flink, was found by Haidinger on the braunite of Elgersburg in Thuringia. Hence the total number of forms so far recognized on crystals of braunite is 16. Their distribution on the crystals of different localities is shown in the following table :—

TABLE 6.

Faces observed on foreign braunites.

Locality.	Number of Forms.	Forms present.
India	10	Given above.
Långban, Sweden [5]	12	*c, a, m, e, o, l, p, x, y, s, t, i.*
St. Marcel, Piedmont [6]	2	*p, x* ; and *e* as twin plane.
Elgersburg, Thuringia [7]	2	*p, s* (*q*).
Wunsiedel, Bayreuth, Bavaria [8]	3	*c, p, s* (*q*).
Windgallen, Uri, Switzerland [9]	3	*a, m, e.*

1 Called *n* by Flink.
2 Called *k* by Flink.
3 Called *h* by Flink.
4 *Loc. cit.*, pp. 5 and 6, (1890).
5 Flink, *loc. cit.*
6 Haidinger, Des Cloizeaux, and Vom Rath, *loc. cit.*
7 Haidinger, *loc. cit.*
8 Haidinger, *loc. cit.* With regard to this locality Haidinger remarks that it is exceedingly problematical, and that the specimens resemble those of Elgersburg ; and as no specimens have since been recorded from Wunsiedel, these crystals are probably correctly regarded as derived from the Thuringian locality.
9 C. Schmidt, *Zeit. Kryst.*, XI, p. 603, (1886).

Physical characters of braunite.

According to Dana's 'System of Mineralogy' braunite shows the following characters:—Cleavage: perfect parallel to the faces of the tetragonal pyramid or octahedron. Fracture uneven to sub-conchoidal. Brittle. H.= 6–6·5. G=4·75–4·82. Lustre submetallic. Colour dark brownish black to steel-grey. Streak same.

In most respects the Indian braunites agree with the above. Thus, of the three specimens of braunite of which the analyses are given below, two have a specific gravity of 4·79, whilst the third, which contains a considerable quantity of magnesia and is therefore not typical, lies outside the limits given above, having G. =4·70. On crystal faces the lustre can perhaps be correctly designated sub-metallic, but on fresh cleavage surfaces it is brilliantly metallic. The colour of the Indian braunites is never brownish black as far as I have seen, but may be either a pure black or a deep steel-grey.

Magnetic characters.

A feature of this mineral which is not, however, mentioned in the diagnosis given by Dana, is that the mineral is invariably slightly magnetic. The strength of this property varies greatly, and is sometimes quite strong. If some of the tiny grains composing the braunite-psilomelane mixtures of the Central Provinces be detached from the ore they can almost invariably be picked up by a small hand magnet, or at least made to move slightly under its influence. The magnetic properties of the Indian braunites might be thought to be due to their contents of iron. This, however, does not necessarily follow; for the specimen (16·815) of which the analysis is given on page 68, though not corresponding very closely in composition to the theoretical braunite (in fact I have separated it as a variety of this mineral), contains only a very small quantity of ferric oxide compared with some of the Indian braunites. It is, however, just as strongly magnetic.

Composition of braunite.

The question as to the chemical composition of braunite has been the subject of repeated discussion, and it cannot be said that even now this point has been satisfactorily settled. The mineral was first distinguished as a separate species by Haidinger in 1826.[1] In this paper he calls the mineral 'brachytypous manganese-ore' and notices specimens from both Elgersburg in Thuringia and St. Marcel in Piedmont. In 1827 he read a

1 *Edin. Jour. Sci.*, IV, p. 48 (Dana); translated into German in *Pogg. Annalen*, VII, p. 234, (1826).

paper before the Royal Society of Edinburgh [1], in which he gives a somewhat fuller account of the mineral and designates it 'braunite' after Braun of Gotha. This is followed by a paper by E. Turner in which is given an analysis of the braunite of Elgersburg in Germany[2]. Turner neglects a residue of silica, which he characterizes as a trace and determines the manganese protoxide by difference. In this way Turner arrives at the conclusion that braunite is a sesquioxide of manganese of the formula Mn_2O_3, or, as he puts it, 'an anhydrous deutoxide of manganese'. Since then only two other analyses have been published that show braunite to correspond to this formula. These are of specimens from Arkansas by R. N. Brackett and W. A. Noyes [3], and Elba by C. Bechi [4], the percentages of silica being 0·18 and 0·75, respectively. As the braunite of Elgersburg was later analysed by Rammelsberg [5] and found to contain 8·63 per cent. SiO_2, it seems as if the only analyses of braunite, corresponding to the formula Mn_2O_3, on which it does not seem possible to cast reasonable doubt are those of the Arkansas and Elba specimens. But it is to be noticed that another analysis of Arkansas braunite shows 9·97 per cent. of SiO_2, the analysis being by W. Elderhorst [6]. Nevertheless, it seems necessary to recognize the possible existence in Nature of a mineral with a composition corresponding to the formula Mn_2O_3; it must be extremely rare. All other observers have obtained a residue of gelatinous silica on dissolving the mineral in hydrochloric acid. From its gelatinous condition it seems as if this silica must have been present not as an impurity, but as a constituent part of the mineral. The subject is well summarized in the already-cited paper of Rammelsberg and in Penrose's book on manganese, pages 151 to 153.

Hermann[7], writing before the essential presence of silica in braunite had been recognized, supposed, in order to account for the fact that braunite is not isomorphous with hematite, Fe_2O_3, that the composition of the non-siliceous braunites is more truly represented by the formula $MnO.MnO_2$, than by Mn_2O_3 : this was on the analogy of the view previously advanced by Berthier [8] that the composition of the protosesquioxide is best expressed as $2MnO.MnO_2$.

1 *Transactions*, XI, p. 132, (1831).
2 *Op. cit.*, p. 167.
3 Penrose, Ann. Rep. Geol. Surv. Arkansas for 1890, Part I, p. 149.
4 *Am. J. Sci.*, 2nd Ser., XIV, p. 62, (1852).
5 *Pogg Ann.*, CXXIV, p. 517, (1865).
6 First Report of a Geological Reconnaissance of the Northern Counties of Arkansas, by D. D. Owen, pp. 164, 165, and 169, (1868) (Penrose).
7 *Jour. f. pr. Chem.*, XLIII, p. 50, (1848), (Rose).
8 *Annales de Chimie et de Physique*, XX, p. 186, (1823), (Rose).

G. Rose [1] took up this idea, and in view of the known presence of silica in most specimens of braunite, attempted to show that SiO_2 and MnO_2 isomorphously replace one another in this mineral. He gives the following as the most general formula of the mineral, allowing in it for the presence of small quantities of various protoxide constituents replacing the manganese protoxide, MnO :—

$$\left.\begin{matrix}MnO\\FeO\\CaO\\MgO\end{matrix}\right\}SiO_2 \quad + \quad \left.\begin{matrix}MnO\\FeO\\CaO\\MgO\end{matrix}\right\}MnO_2$$

He then considers as derivatives of this formula the braunite of Elgersburg, which had not then been shown to contain silica, and the variety of this mineral from St. Marcel in Piedmont, called *marceline* by Beudant [2] in 1832, and analysed by Damour [3]. These two varieties would then have the formulæ :—

$$\text{Braunite} \quad \left.\begin{matrix}MnO\\BaO\end{matrix}\right\}MnO_2.$$

$$\text{Marceline} \quad MnO \left\{\begin{matrix}MnO_2.\\SiO_2\end{matrix}\right.$$

Rammelsberg [4] then analysed the braunite of Elgersburg and found that it contained 8·63 per cent. of SiO_2. He considers that the mineral is an isomorphous mixture of manganic oxide, Mn_2O_3, and manganous metasilicate, $MnSiO_3$, the various protoxides that often enter into the composition of the braunite replacing portions of the MnO of the $MnSiO_3$. He gives as the formula :—

$$3\,Mn_2O_3 + MnSiO_3 = \left.\begin{matrix}\frac{7}{8}\,Mn\\\frac{1}{8}\,Si\end{matrix}\right\}{}_2O_3.$$ [5]

Except for the fact that Rammelsberg regards the oxide portion of the formula to be manganic oxide, Mn_2O_3, this is essentially the formula put forward by Rose, who, however, regards the oxide portion as composed of $MnO.MnO_2$. Rammelsberg draws attention to the analogy between the formula of braunite as he has expressed it and that of ilmenite, which may be written as —

$$m Fe_2O_3 + n(Fe,Mg)O.TiO_2 = (Fe,Ti,Mg)_2O_3.$$

1 *Pogg. Ann.*, CXXI, pp. 318-325, (1864).
2 'Traité élémentaire de Minéralogie', II, p. 188, (Dana).
3 *Annales des Mines*, 4me. Ser., I, pp. 405, 406, (1842).
4 *Loc cit.*, p. 519.
5 The analysis given by Rammelsberg agrees much better with the formula $7Mn_2O_3 + 2MnSiO_3$, than with the one given.

J. D. Dana[1], in order to bring out the crystallographic relation of this mineral to rutile, gives the formula as :—

$$2\,(2MnO.MnO_2) + MnO_2.SiO_2.$$

Later, however, E. S. Dana [2] adopts Rammelsberg's formula ; in the meantime Rammelsberg, as the result of the discovery of the different behaviour of the Mn_2O_3 in manganite, a mineral which is isomorphous with the corresponding iron mineral gothite, from that of the Mn_2O_3 in braunite, when the minerals are subjected to the action of concentrated nitric acid, changes his views [3] and admits the probability that the Mn_2O_3 of braunite is really composed of $MnO.MnO_2$. In this case he says that the formula may be—

$$MnO + \left.\begin{matrix} Mn \\ Si \end{matrix}\right\} O_2$$

Bauer [4] supposes braunite to be an isomorphous mixture of $MnO.MnO_2$ and $MnO.SiO_2$, in which a portion of the MnO is replaced by BaO. Flink[5] in a paper on the Långban braunite gives the formula as $RO.RO_2$, and arranges the analysis he has made of the braunite of this locality as the sum of manganous manganite, $MnMnO_3$, and of metasilicates of Mn, Fe, Ca, and Mg, of the general formula $RSiO_3$.[6]

From a discussion of the various analyses given below I propose to show that it is probable that Flink's method is the correct one and that braunite is to be regarded as an isomorphous mixture of manganites of the general formula $RMnO_3$, and of metasilicates of the general formula $RSiO_3$. This can be stated more generally as —

$$mRMnO_3 + nRSiO_3 ;$$

1 ' System of Mineralogy', 5th Edit., p. 133, (1868).

2 *Op. cit.*, 6th Edit., p. 233, (1892).

3 *Sitzungsberichte der k. preuss. Akad. Wiss.*, 1885, I, pp. 97-100.

4 ' Lehrbuch der Mineralogie', pp. 317, 318, (1886), (Penrose).

5 *Ak. H. Stockh. Bihang*, XVI, (2), No. 4, p. 9, (1890).

6 Since this was sent to the press I have been able to obtain copies of M. Al. Gorgeu's paper ' Sur les oxydes de manganese naturels ', issued in three parts. These three parts deal with the following minerals :—

Part I. *Bull. de la Soc fr. Mineralogique*, III, pp. 21-31, (1890). Psilomelanes and wads.

Part II. *Bull. de la Soc. Chimique de Paris*, IX, pp. 496-502, (1893). Polianites and pyrolusites.

Part III. *Ibid.*, pp. 650-661. Manganites, hausmannites, and braunites.

As the result of analyses of, and experiments on, braunites from St. Marcel in Piedmont, and Schwarzenbourg in Prussia, Gorgeu concludes (noticing also the analyses of Rammelsberg and Damour) that braunite can perhaps be regarded as representing an acid salt with the general formula $(Mn, Si)O_2\,RO$, in which the acid portion is formed by a combination, in slightly variable proportions, of silicic and manganous acids, and in which the basic portion consists of a number of oxides, amongst which MnO largely predominates. He finds that this combination is only broken up by heat when the temperature exceeds that corresponding to a cherry-red.

In all the analyses considered the ratio of $m : n$ lies between the limits 3 : 1 and 4 : 1. As manganese is the predominant basic constituent the formula can be more definitely stated as—

$$m\,MnMnO_3 + n\,MnSiO_3.$$

On the supposition, which has yet to be proved, that the Si in a metasilicate is isomorphous with the Mn in a manganite, this formula can be further simplified to —

$$Mn(Mn,Si)O_3.$$

The most general ratio of m to n is perhaps 3 : 1 ; so that the formula of braunite can be conveniently expressed as —

$$3MnMnO_3 + MnSiO_3.$$

In attempting to find out to which of the various formulæ proposed the Indian braunites correspond I have three analyses to reply upon. These are shown below. The specimen A. 345 was obtained from the ore heaps at Garividi station of the ore quarried from Garividi deposit, where, as is noticed on page 1055, all the ore is of detrital character, the ore-body *in situ* not having yet been uncovered. This quarry, however, happens to be the locality from which the best specimens of braunite are to be obtained in the Vizagapatam district. The specimen was black and lustrous, showing perfect cleavage and the most brilliant reflections from these cleavage faces. It was a portion of one crystal showing a cleavage face over 3 inches long. The portion of it broken off for analysis weighed 25 grammes, and had a specific gravity of 4·79. This braunite can be taken as typical of that formed chemically in the deposits of the kodurite series. The second specimen, No. 1110, was obtained by carefully breaking up two or three crystals of the braunite occurring in the albite veins at Kácharwáhi in the Nágpur district, and making sure that there was no albite in the specimen taken for analysis. This mineral in outward appearance was identical with the Garividi specimen, showing the same black lustrous cleavage. The weight taken for analysis was 2·69 grammes, of a specific gravity of 4·79. This braunite can be taken as typical of that which occurs in veins of igneous origin. The third specimen, 16·815, was obtained after a tedious separation, carried out by Mr. T. R. Blyth of the Geological Survey of India, from a rock composed of this mineral, winchite, calcite, and quartz, sent by Mr. H. J. Winch from Kájlidongri in Jhábua State, Central India. The product of the separation consisted of a large number of tiny grains of a lustrous black mineral that under the microscope showed many triangular faces, indicating an octahedral shape for the crystals. From the fact that this mineral was found to be decidedly

magnetic, and the fact that the amphibole, winchite, with which it was associated contained a considerable proportion of magnesia, it was supposed that analysis would show this mineral to be jacobsite. The amount obtained for analysis was 3·05 grammes; Mr. Blyth found the specific gravity, by Penfield's method, to be 4·70. Analysis has, however, shown that the mineral contains 10 per cent. of SiO_2 and that it is allied to braunite, if it cannot be actually relegated to this species. It is to be regretted that no analysis has yet been made of the braunite that occurs in the braunite-psilomelane mixtures of the C. P.

The results of these analyses are shown below. The Garividi and Kácharwáhi specimens were analysed by Messrs. J. and H. S. Pattinson of Newcastle-on-Tyne, and the Kájlidongri specimen by Mr. Blyth.

TABLE 7.

Analyses of Indian braunites.

	Garividi.	Kácharwáhi.	Kájlidongri.
Number of specimen .	A. 345.	1110.	16·815.
Manganese peroxide .	37·06	40·23	40·93
Manganese protoxide .	36·72	41·85	37·98
Ferric oxide . . .	14·14	5·50	1·45
Alumina . . .	0·90	0·44	0·14
Baryta . . .	0·56	0·53	0·09
Lime	0·78	1·13	3·85
Magnesia . . .	0·56	0·38	4·36
Potash	0·13	0·16	..
Soda	0·21	0·15	..
Silica (combined) . .	8·25	8·60	10·26
Sulphur . . .	0·03	0·04	..
Phosphoric oxide . .	0·07	0·08	..
Arsenic oxide . .	*Nil*	*Nil*	..
Cobaltous oxide . .	0·05	0·20	..
Nickelous oxide . .	*Nil*	*Nil*	..
Cupric oxide . . .	0·03	0·05	..
Lead oxide . . .	*Nil*	*Nil*	..
Zinc oxide . . .	*Nil*	*Nil*	..
Titanic oxide . .	0·06	0·03	..
Chlorine and fluorine .	*Nil*	*Nil*	..
Combined water . .	0·25	0·38	..
Moisture at 100°C . .	0·25	0·10	1·57
Carbon dioxide . .	*Nil*	*Nil*	..
	100·05	99·85	100·63
Manganese . . .	51·88	57·86	55·29
Iron	9·90	3·85	1·01
Specific gravity . .	4·79	4·79	4·704

For the purpose of calculating from these figures it is found to be necessary to assume that the ferric oxide replaces an equivalent quantity of manganese sesquioxide, Mn_2O_3, and that the oxides of barium, calcium, and magnesium, replace equivalent amounts of manganese protoxide, MnO. Neglecting, then, all the constituents of the analyses, except the MnO_2, MnO, Fe_2O_3, BaO, CaO, MgO, and SiO_2, and replacing the oxides of iron, barium, calcium, and magnesium, by equivalent amounts of manganese oxides, and splitting up the Mn_2O_3 so obtained from the Fe_2O_3 into MnO and MnO_2, the composition of the three specimens works out as follows :—

	Garividi.	Kácharwáhi.	Kájlidongri.
MnO	45·22	46·64	51·21
MnO_2	44·75	43·22	41·72
SiO_2	8·25	8·60	10·26
	98·22	98·46	103·19
Manganese	63·32	63·45	66·05
Available oxygen	8·23	7·95	7·67

Reduced to 100, these correspond to :—

	Garividi.	Kácharwáhi.	Kájlidongri.
MnO	46·04	47·37	49·64
MnO_2	45·56	43·90	40·42
SiO_2	8·40	8·73	9·94
	100·00	100·00	100·00
Manganese	64·47	64·43	64·00
Available oxygen	8·38	8·07	7·43

The formula for braunite usually given in text-books of mineralogy is that of Rose and Rammelsberg (see page 65); but this corresponds to 9·98 per cent. of silica. Although some of the published analyses show this amount, many of them show a considerably smaller quantity of SiO_2. This probably means that the relation of Mn_2O_3 to $MnSiO_3$ is not always 3 : 1, but is sometimes greater than this value.

Consequently I have given below the composition of braunites corresponding to ratios of 3 : 1, 7 : 2 and 4 : 1, respectively :—

Formula.	$3Mn_2O_3.MnSiO_3$.	$7Mn_2O_3.2MnSiO_3$.	$4Mn_2O_3.MnSiO_3$
MnO	46·91	46·69	46·51
MnO_2	43·11	44·49	45·58
SiO_2	9·98	8·82	7·91
	100·00	100·00	100·00
Manganese . . .	63·59	64·29	64·85
Available oxgyen . .	7·93	8·18	8·38

Or, if the manganese and oxygen be stated in terms of MnO and Mn_2O_3, the figures are as follows :—

MnO	11·73	10·38	9·30
Mn_2O_3 . . .	78·29	80·80	82·79

On comparing with these figures the analyses of Indian braunites given above it appears that the Garividi specimen corresponds almost exactly to a formula lying half-way between the formulæ corresponding to the second and third columns. This formula is $15Mn_2O_3.4MnSiO_3$, the ratio between Mn_2O_3 and $MnSiO_3$ being $3\frac{3}{4} : 1$ instead of either $3\frac{1}{2} : 1$ or 4: 1.

The Kácharwáhi specimen, on the other hand, corresponds very closely to the formula $7Mn_2O_3.2MnSiO_3$, the chief points to notice, in comparing the figures given on page 69 with those for the formulæ given above, being the amounts of manganese, silica, and available oxygen, the amounts of the oxides of manganese being of less value in making this comparison because a small error in the determination of the available oxygen produces a considerable change in the ratios of the peroxide to protoxide of manganese.

The figures, as given on page 69, deduced from the Kájlidongri analysis, correspond most closely with the formula in the first column above, namely to $3Mn_2O_3.MnSiO_3$. The most noticeable deviation from the theoretical formula is in the ratio of the oxides to one another. This, however, corresponds to a relatively small error in the determination of the available oxygen.

From the consideration of the foregoing three analyses it appears

that the three different examples of braunite correspond to the three following formulæ :—

Garividi	$15Mn_2O_3.4MnSiO_3$	=	$19MnO.15MnO_2.4SiO_2$	= $19[MnO + (Mn,Si)O_2]$
Kácharwáhi	$7Mn_2O_3.2MnSiO_3$	=	$9MnO.7MnO_2.2SiO_2$	= $9[MnO + (Mn,Si)O_2]$
Kájlidongri	$3Mn_2O_3.MnSiO_3$	=	$4MnO.3MnO_2.SiO_2$	= $4[MnO + (Mn,Si)O_2]$

It will be seen from the above that although the formulæ of these three specimens of braunite show three different ratios of Mn_2O_3 to $MnSiO_3$, yet the number of molecules of the manganese protoxide is equal in each case to the sum of the number of molecules of the dioxides MnO_2 and SiO_2, so that the three formulæ can be re-arranged as 19, 9, and 4 times the formula $MnO + (Mn,Si)O_2$; the difference between the three braunites lies in the ratio of Mn to Si in the (Mn, Si) group, being 15 : 4, 7 : 2, and 3 : 1, that is $3\frac{3}{4} : 1$, $3\frac{1}{2} : 1$ and 3 : 1 in the three cases. The formula $MnO + (Mn,Si)O_2$ may thus be taken as the general formula of braunites free from appreciable quantities of replacing constituents. It must be remembered, however, that in making the above calculations, portions of the manganese were put in the place of the oxides of iron, barium, calcium, and magnesium, returned in the original analysis. At first sight it might seem a difficulty that the iron was returned in the original analysis as Fe_2O_3, and that there is no sesquioxide group in the above formula for braunite that the iron could replace. It must be remembered, however, that there is no means of telling in what condition the iron really was in the original mineral. To fit in with this formula it must have been in the ferrous condition with a corresponding proportion of the manganese originally returned as protoxide in the peroxide form. On this view the general formula that takes in all the above varieties is—

$$(Mn,Fe,Mg,Ca,Ba)O + (Mn,Si)O_2.$$

In most cases the amounts of baryta, lime, and magnesia are small, so that, although it is necessary to take them into account in the calculations, they can be omitted from the formula. The most usual formula for braunite will then be—

$$(Mn,Fe)O + (Mn,Si)O_2.$$

In the case of braunites containing only an insignificant amount of iron the formula can be further simplified into—

$$MnO + (Mn,Si)O_2.$$

Since the ratio between the Mn and Si in the (Mn, Si) group is a variable one it is evident that there are two further possible simplifications

of the above formula. One of these is when the ratio of Mn to Si is infinity. Then the formula becomes—

$$MnO + MnO_2 = Mn_2O_3,$$

thus taking in the doubtful cases of minerals having the simple formula Mn_2O_3. The other alternative is when the ratio of Si to Mn is infinity. The formula then becomes—

$$MnO + SiO_2 = MnSiO_3,$$

which is the formula of rhodonite.

In pursuing this variation of the formula to its logical conclusion I am not suggesting that there is necessarily any direct connection between braunite and rhodonite, especially as one is tetragonal and the other triclinic in crystallization. To establish this connection it would probably be necessary to prove the existence of a series of compounds of gradually increasing ratio of Si to Mn, corresponding, of course, to an increase in the ratio of $MnSiO_3$ to Mn_2O_3 in the other method of expressing the formula of braunite. I have considered this general formula for braunite to show the connection between the different varieties of this mineral, as otherwise it might be considered necessary to propose different names for minerals of different formulæ. I do not, however, suppose that it is a true formula as regards structure. It is more probable that a change in the ratio of Si to Mn indicates a change in the number of molecules of $MnO + SiO_2$ relative to molecules of $MnO + MnO_2$, and not a change within the molecule itself.

The formulæ of the above specimens of braunite, making due allowance for the more important of the replacing constituents, work out as follows according to the $mR_2O_3 + nMnSiO_3$ method :—

Garividi . . .	$15(Mn,Fe)_2O_3.4MnSiO_3$.
Kácharwáhi . . .	$7(Mn,Fe)_2O_3.2MnSiO_3$.
Kájlidongri . . .	$3Mn_2O_3$. $(Mg,Ca)\,SiO_3$.

In the first two cases the alkaline earths are not present in sufficient quantity to be entered up in the formula. In the third analysis the iron is sufficiently insignificant in amount to be omitted from the formula ; but it so happens that the MgO and CaO are just a little more than sufficient to replace all the R in the $RSiO_3$ group. Hence it seems that this is to be regarded as a rather unusual variety of braunite, exhibiting, moreover, a lower specific gravity than usual, namely 4·70, this being, of course, due to the replacement of manganese by magnesium and calcium.

To see how the braunites of other countries fit in with the formulæ given above I have reduced some of the published analyses of foreign braunites into terms of oxides of manganese and silica, by replacing lime,

magnesia, baryta, and oxide of iron, with equivalent amounts of manganese oxides, and then reducing the whole to 100 in exactly the same way as was done above in the case of the Indian braunites. Of the five examples given below, all except that by Igelström are in papers already quoted.

	Elgersburg.	St. Marce[1].	Jakobsberg.	Långban.	Arkansas.
Analyst.	Rammelsberg.	Damour.	Igelström.[1]	Flink.	Elderhorst.
MnO . . .	46·90	47·63	46·80	49·04	45·04
MnO_2 . . .	44·38	44·69	44·51	41·16	44·94
SiO_2 . . .	8·72	7·68	8·69	9·80	10·02
	100·00	100·00	100·00	100·00	100·00
Manganese . .	64·37	65·16	64·37	63·99	63·28
Available Oxygen .	8·16	8·12	8·19	7·28	8·02
Specific gravity . .	4·75; 4·82[2]	4·75	——	4·72	——

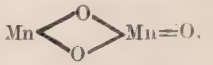
On comparing these figures with those given on page 70 for the various formulæ to which this mineral may correspond, it is seen that the Langban and Arkansas braunites correspond to the formula $3Mn_2O_3.MnSiO_3$, the Elgersburg and Jakobsberg braunites to $7Mn_2O_3.2MnSiO_3$, and the St. Marcel specimen to the third formula $4Mn_2O_3.MnSiO_3$. The analysis that shows the greatest deviation from the formula to which it is closest is the Langban one; it is evident that this deviation is due to too low a percentage of available oxygen, this altering the ratio of the manganese protoxide to peroxide considerably.

The other published analyses to which reference may be made are ones by Cap. von Ewreinhoff[3] of St. Marcel braunite, showing 10·16 per cent. SiO_2 as the mean of two determinations; ones by Damour, also of St. Marcel mineral, showing 10·24 per cent. of SiO_2 as the mean of three determinations; and one by Tönsager[4] of braunite from Botnedalen, Telemarken, Norway, in which was found 6·22 per cent. of SiO_2 and 3·62 per cent. of insoluble rock powder. It is noticeable that these two add up nearly to 10 per cent. From the silica percentages it seems as if the braunites of these localities correspond to the formula

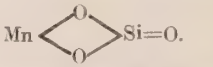
[1] *Bulletin de la Soc. Min. de France*, VIII, p. 423, (1885).
[2] Haidinger, *Trans. Roy. Soc. Edin.*, XI, p. 133.
[3] *Pogg. Ann.*, XLIX, p. 208, (1840).
[4] *Op. cit.*, LXV, p. 281. (1845).

$3Mn_2O_3.MnSiO_3$; so that some of the St. Marcel mineral must conform to this formula and some to the formula $4Mn_2O_3.MnSiO_3$.

The question arises as to whether all the braunites can be fairly said to conform with one of the definite formulæ, in which the ratio of Mn_2O_3 to $MnSiO_3$ is either 3 : 1, 7 : 2, or 4 : 1 ; or whether the admixture of these two portions of the braunite is really isomorphous within the limits 3 : 1 and 4 : 1, so that the ratio of Mn_2O_3 to $MnSiO_3$ may have any value between these two limits. In Treadwell and Hall's Analytical Chemistry, I, page 115, reasons are given for supposing that the structural composition of Mn_2O_3 may be represented in the following manner



so that it is a manganous manganite analogous in composition to manganous metasilicate—



This supposition is also supported by G. Bertrand[1] in order to allow of the replacement of Mn by Ba in the basic portion of the mineral, and of Mn by Si in the acid portion of the mineral. This is of course practically equivalent to a return to the idea of Rose that the SiO_2 can isomorphously replace MnO_2. It seems indeed as if the structure of braunite can be very conveniently explained in this way, according to which it would be an isomorphous mixture of molecules of $MnMnO_3$, $CaMnO_3$, $BaMnO_3$, $FeMnO_3$, $MnSiO_3$, $FeSiO_3$, etc., in varying proportions, the limits to the replacement of molecules of the form $RMnO_3$ by molecules of the form $RSiO_3$ being that prescribed by the ratios 3 : 1 and 4 : 1. It is probable, in view of the fact that the varieties of braunite yet analysed do not show any very large amount of replacement of $MnMnO_3$ by $FeMnO_3$ or other similar molecules, that there is also a limit to this replacement consistent with the mineral still possessing the form of braunite. The extent to which this replacement of one molecule by another can take place so that the mineral still exhibits the characteristics of braunite is a point that will need a large amount of investigation and one that can probably be solved only by an attempt to make the different varieties artificially.

If, however, the views expressed above be correct one would expect the replacement of molecules of the form $RMnO_3$ by ones of the form $RSiO_3$ to take place gradually between the limits 3 : 1 and 4 : 1. The

[1] *Revue générale de Chimie*, VIII, p. 208, (1905).

figures that are the most explicit in this respect are those for the SiO_2. If the replacement be gradual, the amounts of silica found in a sufficiently large series of analyses of braunite should be distributed evenly over the whole of the range between the percentages corresponding to the two limiting forms of braunite, namely between the values 7·91 and 9·98. The eight values of the silica given above can be arranged in the following order—

7·68	near 7·91 for $4Mn_2O_3.MnSiO_3$.
8·40	
8·69, 8·72, 8·73,	near 8·82 for $7Mn_2O_3.2MnSiO_3$.
9·80, 9·94, 10·02,	near 9·98 for $3Mn_2O_3.MnSiO_3$.

It will be seen that all except one of these group themselves close to the values for one of the fixed ratios 3 : 1, 7: 2, and 4 : 1. Hence it would seem that braunites of these definite ratios, only, exist, and that the mixture is not truly isomorphous, owing perhaps to a definite combination taking place betweem the $MnMnO_3$ and the $MnSiO_3$ when the composition corresponds to these definite ratios. This is of course a question that can only be settled when a much larger number of analyses have been made. I am inclined to think that the grouping shown by these analyses may be accidental and that the admixture of $MnMnO_3$ and $MnSiO_3$ may take place in any proportions between the limits 3 : 1 and 4 : 1.

In dealing with the analyses of composite specimens of ore scattered through the descriptive portion of this Memoir, I have assumed for the braunite the most generally accepted formula, namely $3Mn_2O_3.MnSiO_3$, containing a percentage of 9·98, or practically 10, of silica. The advantage of this formula is that if the combined silica in the analysis be taken and multiplied by 10 the product gives very closely the percentage of braunite in the ore. And in the Central Provinces, where the ores are mixtures of braunite and psilomelane, it is found that by taking this formula the ore works out almost exactly in most cases to a mixture of braunite and psilomelane in a proportion that agrees with the appearance of the specimen. Consequently if the complete analysis of a piece of Central Provinces ore be taken and the combined silica multiplied by 10, this will give the percentage of braunite ; and the remainder, after taking out the P_2O_5 as apatite and any free silica as quartz, will be psilomelane ; or as the amounts of apatite and quartz are usually insignificant, the remainder after subtracting the braunite can be reckoned to be psilomelane. This method can even be applied to the calculation of the approximate composition of a sample of which only a partial analysis is available. Thus, the partial analysis (No. 3) of Rámdongri ore given on page 858 shows 5·19 % of combined silica. This corresponds to 51·9 per cent. or roughly 52 per cent. of braunite,

leaving a remainder of 48 per cent., which, as the amounts of free silica, phosphoric oxide and moisture are not large, can be taken as roughly corresponding to the percentage of psilomelane in the ore. That is the composition of the sample can be taken as roughly 52 per cent. of braunite, and 48 per cent. of psilomelane. The method of calculating out a complete analysis into terms of its mineral composition is explained on page 108; many examples of such re-arranged analyses will be found scattered through the pages given up to the description of the deposits of the Nágpur district.

Occasionally the percentage of braunite calculated in this way seems to be considerably less than the aspect of the specimen would lead one to expect. An example is the analysis of a specimen of coarsely crystallized ore from Lohdongri given on page 917. This ore would seem to contain at least 80 per cent. of braunite. Calculation in the ordinary way only shows a percentage of 68·5 per cent. of braunite. This probably means that the braunite in this ore has one of the other formulæ, probably $7Mn_2O_3.2MnSiO_3$ containing only 8·8 per cent. of silica, instead of 10 per cent. as in the braunites of the formula $3Mn_2O_3.MnSiO_3$. This would give a percentage of 77·4 of braunite; whilst the formula $4Mn_2O_3.MnSiO_3$, corresponding to 7·9 per cent. of silica, would give 86·3 per cent. braunite in the ore, and one of these two latter figures would seem to correspond more exactly with the aspect of the ore than the first.

Appendix.—Since the foregoing was sent to the press, Mr. Blyth has been able to analyse the braunite of Sitapár in the Chhindwára district, Central Provinces. The mineral taken for analysis was obtained from the complex ores of this locality, consisting of sitaparite, hollandite, braunite, pyrolusite, and an arsenate. The braunite occurs in small black lustrous grains. The amount obtained fit for analysis was 1·14 grammes. The specific gravity was found to be 4·798. The result of the analysis is shown below :—

Analysis of Sitapár braunite.

Specimen No. 843 C4.

Manganese peroxide	37·10
Manganese protoxide	41·10
Ferric oxide	7·92
Alumina	0·92
Baryta	trace
Lime	4·28
Magnesia	0·94
Silica	8·52
Moisture at 100°C.	0·10
	100·88
Manganese	55·28
Iron	5·54

By converting the lime and magnesia into equivalent amounts of manganese protoxide, and the ferric oxide into its equivalent of Mn_2O_3, the figures given in column No. 1 below are obtained. In column No. 2 these figures are given reduced to 100.

	No. 1.	No. 2.
MnO	51·69	50·87
MnO_2	41·41	40·75
SiO_2	8·52	8·38
	101·62	100·00
Manganese	66·20	65·16
Available oxygen	7·62	7·50

On comparing the figures given in column 2 with those for the three varieties of braunite given on page 70, it will be seen that as regards the silica percentage, 8·38, the Sitapár braunite lies about half-way between the formulæ in which the ratios of Mn_2O_3 to $MnSiO_3$ are 7 : 2 and 4 : 1, respectively, the actual ratio corresponding to this silica percentage being 15 : 4, as in the Garividi specimen. The amounts of MnO, MnO_2, and available oxygen are, however, considerably different from what they should be if the braunite has this formula. This difference can be easily explained on the supposition either that there is an error of 0·78 per cent. in the oxygen determination, or that all the protoxides do not form a portion of the braunite, and so should not all have been converted into manganese protoxide in the foregoing calculations. The formula of this braunite on the supposition of an error in the oxygen determination would be $15Mn_2O_3.4MnSiO_3$; whilst on the supposition that a portion of the protoxides of lime and magnesia does not form a portion of the braunite, the formula would be $4Mn_2O_3.MnSiO_3$.

Polianite.

Polianite is a mineral crystallizing in the tetragonal system in forms isomorphous with tin-stone. It has a composition represented by the formula MnO_2, is too hard to be scratched by a penknife (H. = 6-6·5) and has a specific gravity of 4·83-5·03. Its colour is light steel-grey to iron-grey, with a black streak. This is one of the rarest of the oxide minerals of manganese and is found at Platten in Bohemia. It has not yet been for certain identified amongst the Indian ores.

Some specimens of manganese-ores were recently sent to the Geological Survey Office from the Bikonhalli deposit (known as Norton's Block), Shimoga district, Mysore, by Mr. Claude Fawcitt, chemist to the New Mysore Manganese Company. Amongst them is one, the characters of which suggested polianite. In general colour

it is light steel-grey, with a dead-black streak. It is slightly magnetic, has a hardness of 6·5 and specific gravity of 4·80, determined on a piece weighing 34 grammes. This piece was powdered and the analysis kindly undertaken by Mr. Fawcitt. The result was as follows :—

MnO_2	92·55
MnO	2·69
Fe_2O_3	1·60
Al_2O_3	0·70
CaO	0·61
MgO	0·25
P_2O_5	0·07
CO_2	trace
SiO_2	0·80
Combined water (by difference)	0·73
	100·00

The unusually large amount of manganese peroxide shows that the mineral is different from the other manganese-ores found in India ; of these the only mineral that contains such a high percentage of MnO_2 is pyrolusite, which is much too soft for the present mineral. Considering this fact there seems no alternative to regarding the mineral as polianite rendered impure by the presence of some $7\frac{1}{2}$ per cent. of foreign material, present either as another mineral mechanically mixed with the polianite, or as impurities mechanically included in it. If the former be the case then it is probable that the other mineral is braunite, in which the silica would be contained. [A careful examination of the specimen with a lens seems to show that it is made up of two constituents of which one might be braunite and the other hollandite, the latter being present in by far the larger amount. But the analysis renders it improbable that this is the composition of the ore and consequently it is necessary to suppose that the mineral that suggests hollandite is really polianite. I shall not, however, be satisfied with this determination until I have obtained some definitely crystallized specimens of the mineral showing the crystalline form of polianite.]

Pyrolusite.

Pyrolusite is the peroxide of manganese, MnO_2, containing, when theoretically pure, 63·22 per cent. of manganese. It crystallizes in the orthorhombic system in forms that are supposed to be the result of the formation of this mineral from manganite by dehydration ; the manganite ($Mn_2O_3.H_2O$) giving up its water, with the production of pyrolusite (MnO_2) often containing a certain proportion of residual water. At the same time the manganite

Characters.

loses its hardness (4) and the resultant pyrolusite is probably only an aggregate possessing the outward shape of the manganite, but having the hardness characteristic of pyrolusite, namely 2 to 2·5, this mineral being very soft and soiling the fingers. Its specific gravity is given as 4·73-4·86. In colour the mineral varies from black to steel-grey and bluish-grey with a black streak. The lustre of the mineral is metallic.

In India this mineral is found at a large number of localities, at some of them in considerable quantities. In Mallet's Mineralogy of India, pages 57 to 59, an account is given of the various occurrences of this mineral discovered up to the time that work was written, (1887).

I do not propose to notice in this place all the occurrences of this mineral in India ; for it would be very tedious and take up a large amount of space ; the more important of them must suffice. References to this mineral will also be found throughout the descriptive part of this Memoir, and a reference to them can be obtained from the index.

Occurrence.

It is a pretty common mineral in the manganese-ore deposits of the Vizagapatam district, that is in those derived from the rocks of the kodurite series. Here it occurs more or less massive as a bluish-black ore of fine grain. This ore often exhibits little cavities lined with silvery black mammillations of the same mineral. An analysis of a picked specimen of this ore is given in the table on page 82. Sometimes the ore is found in sufficient quantities to be stacked separately from the other ores of the mine. This I saw being done at Kodur. In the mines of this area the pyrolusite seems to be most commonly formed by the replacement of the quartz-felspar-rocks accompanying the manganese-silicate-rocks, from which the replacing manganese is derived. A figure illustrating this method of formation is given on page 1085.

In the manganese-ore deposits of the gondite series, that is those occurring in the Central Provinces and Jhábua, this mineral is the least common of the three common minerals of manganese, braunite, psilomelane, and pyrolusite. In fact at a large proportion of the deposits it is not found at all, except perhaps as traces ; and of all the deposits of this type the only one at which it occurs in any quantity is Kurmura or Poñwárdongri in the Bhandára district, where there was a huge upstanding mass of ore composed of this mineral and psilomelane. The pyrolusite is fine-grained soft and blackish (see page 752).

At Páli, in the Nágpur district, there is an occurrence of very fine and pure pyrolusite in cavities in crystalline limestone, in which it has been

deposited after the formation of the limestones, which contain piedmontite,* either so as to fill in cavities dissolved out by percolating waters, or by the metasomatic replacement of the limestone under the influence of percolating manganiferous solutions. This deposit has been to a certain extent quarried with the extraction of a considerable quantity of very pure mineral. An analysis of a sample of the mineral is given on page 957, and an analysis of a picked piece of the ore in the table on page 82. The latter analysis shows the ore to be very pure pyrolusite, the most noticeable feature being the extremely small quantity of iron, namely 0·04 per cent. Such an ore is admirably suited for glass manufacture, for which it would probably fetch a high price. The ore itself is found as beautiful concentric mammillary specimens reflecting a silky black lustre from the rounded surfaces of the mammillations, which are often of considerable size, namely one inch or more across. Plate 3 shows a piece of this ore.

Amongst the ores formed by replacement at the outcrops of rocks of the Dhárwár series, pyrolusite is very commonly found, as for example, at Tawargatti and Chik-Vadvati in the Dhárwár district (pages 642, 645); in the manganiferous area south of Cháibása in the Singhbhum district (page 619); at numerous localities in the Jabalpur district, especially in the rocks known as the Gosalpur quartzites (pages 811—814); and in most of the deposits of Mysore and some of those of Sandur.

Pyrolusite, for analyses of which see pages 657, 659, is also found at Sivarájpur in the Panch Maháls district, Bombay. These ores seem to have been formed by the replacement at the surface of the quartzites of the Chámpáner series, the equivalent of the Dhárwárs of other parts of India.

In the ores of lateritic origin pyrolusite is also one of the commonest minerals and is to be found at all the localities where ores of this origin are found. For a list of these areas see page 385. There is nothing of especial interest to notice about these ores except that they frequently show open spaces or cavities lined with small stumpy prismatic or flattened crystals which sometimes seem to be proper pyrolusite and at others seem to be intermediate between manganite and pyrolusite. From their crystalline shape they may once have been manganite. [A good example of pyrolusite formed by the alteration of manganite is figured on Plate 22, Vol. XXXIII, *Records of Geological Survey of India*, the specimen figured coming from Rámandrug in the Sandur Hills; but this is not from true laterite]. Of the lateritic pyrolusites perhaps the

Photo. by H. B. W. Garrick. *Calcutta Phototype Co.*

PYROLUSITE; FROM PÁLI, NÁGPUR DISTRICT, C. P. ½ NATURAL SIZE.

most famous is that of Gosalpur in the Jabalpur district, Central Provinces, for analyses of which see page 813. The masses of pyrolusite found at this place are sometimes as much as 1 to 1½ feet in diameter. When broken open they are usually found to be partly cavernous with small crystals of pyrolusite lining the cavities. Of the fine specimens in the Geological Museum, Calcutta, it is not, however, certain which have been derived from the laterite at Gosalpur and which from the nests and pockets of this mineral that occur in the Gosalpur quartzites. Fair quantities of pyrolusite have also been found at Mansakra in the same district.

Pyrolusite is also sometimes formed as a recent deposit, for an example of which the occurrence at Pán Kuán in the Dhár Forest may be cited (page 675 and Plate 15). Here the mineral is associated with what is probably tufa.

The black dendritic markings of manganese oxide often found on the bedding and parting planes of rocks are usually referred to pyrolusite; the best Indian examples are those found on the bedding planes of Vindhyan sandstone; see Plate 4. which is only ⅕ natural size. Dendrites are often found in the Indian manganese mines.

Analyses.

In the following table I give some analyses of picked specimens of Indian pyrolusites. The first specimen was sent from Bikonhalli in the Shimoga district, Mysore, by Mr. C. S. Fawcitt. The pyrolusite formed a magnificent black lustrous crust of small crystals resting on cavernous ore composed of limonite, pyrolusite, psilomelane, and manganite (?). Some of these crystals were detached and carefully picked. The analysis was kindly undertaken by Mr. Fawcitt. The second specimen was sent by Mr. H. J. Winch from Ghatia in Banswára State, Rájputána. It showed some rather dull, longish, prismatic crystals of nearly square form implanted on some fine-grained manganese-ore, probably composed of a mixture of braunite and psilomelane. These prisms gave a black streak, were scratched by fluorite, and gave off a little water in a closed tube. The specific gravity of some of these detached prisms was found to be 4·94, a little high for pyrolusite. The analysis of the picked sample was undertaken by Mr. Fawcitt. The third specimen was obtained from a heap of picked ore at Kodur in the Vizagapatam district, Madras. It was a fine-grained crystalline piece of ore with cavernous spaces lined with shining mammillations of pyrolusite. The piece taken for analysis was some two inches in diameter, but its specific gravity was not determined on account of the soft and friable character of the mineral. This

specimen was analysed by Messrs. J. and H. S. Pattinson of Newcastle-on-Tyne. The fourth specimen was a piece of the radiate-concentric pyrolusite of Páli in the Nágpur district, referred to above. It was analysed at the Imperial Institute, London, where the specific gravity was found to be 4·88, the piece used being of some 2 inches in diameter. The analyses are given below :—

TABLE 8.

Analyses of Indian pyrolusites.

	Bikonhalli, Shimoga.	Ghatia, Banswára.	Kodur, Vizagapatam.	Páli, Nágpur.
	K. 193.	1707 / 10-4-07 No. 4	A. 197.	932.
MnO_2	96·73	97·04	92·31	95·57
MnO	0·57	0·43	1·82	0·41
Fe_2O_3	0·23	0·03	0·07	0·06
Al_2O_3	0·18	0·17	0·27	0·43
BaO	..	0·07	0·99	1·34
CaO	0·66	0·90	0·31	0·00
MgO	0·76	0·47	0·05	0·09
K_2O	..	*nil*	0·31	trace
Na_2O	..	*nil*	0·11	0·13
SiO_2	0·42	0·41	0·50[2]	0·33[2]
Sulphur	..	..	0·016	..
P_2O_5	..	..	0·956	0·01
As_2O_5	..	..	0·009	0·012
CoO	..	..	0·10	0·016[3]
NiO	..	..	*nil*	..
CuO	..	..	0·005	..
PbO	..	..	*nil*	..
ZnO	..	..	0·10	..
Combined water	0·45[1]	0·35	2·00	1·46
Moisture at 100°C.	..	..	0·25	0·12
Carbon dioxide	..	..	*nil*	0·09
	100·00	99·87	100·176	100·068
Manganese	61·57	61·68	59·78	60·79
Iron	0·16	0·02	0·05	0·04
Phosphorus	..	..	0·42	0·004
Specific gravity	..	4·94	..	4·88

[1] By difference.
[2] All combined silica.
[3] Mainly cobalt oxide.

Photo. by H. B. W. Garrick. *Calcutta Phototype Co.*

DENDRITES OF MANGANESE OXIDE ON UPPER VINDHYAN SANDSTONE, PANNA, CENTRAL INDIA.
$\frac{1}{3}$ NATURAL SIZE.

Manganite.

Manganite is a hydrated oxide of manganese having the formula $Mn_2O_3.H_2O$. It crystallizes in the orthorhombic system in prismatic crystals usually exhibiting several different prism faces; the termination is usually a basal plane, although this is sometimes absent, pyramid and dome faces being developed instead. The crystals are often many times longer than broad, then assuming a needle-like aspect. The colour is stated to be steel-grey to iron-black and the lustre sub-metallic, with the streak reddish brown to nearly black. Hardness = 4. Specific gravity = 4·2–4·4. When pure the mineral contains 62·50 per cent. of manganese and 10·23 per cent. water.

Characters.

According to Mallet a specimen of this mineral has been obtained from the Political Agent at Gwalior, and hence presumably from that neighbourhood.[1] I have shown elsewhere that this specimen[2] is probably only pyrolusite, although the crystals may be pseudomorphous after manganite.

Occurrence.

In a paper in the *Records of the Geological Survey of India*, Vol. XXXIII, pages 229-232, I have described and figured an example, there supposed to be manganite, occurring as a lining to a geode found on the outcrop at Rámandrug in the Sandur Hills. At the time this paper was written this was the only known specimen of this character. Since then, however, Mr. Aubert, who obtained that specimen, has presented to the Geological Survey several more similar specimens from the same locality. The specimen described in the paper exhibits well the long needle-like habit, showing usually the faces of a prism, sometimes accompanied by other bevelling prisms, with for termination either the basal plane or, more rarely, a couple of minute faces that suggest the macrodome. The mineral differs from typical manganite in that it does not seem to give off, when heated in a closed tube, a large enough quantity of water, probably owing to incipient change to pyrolusite. It is noticed that the perfect cleavage of manganite parallel to the brachypinacoid *b* (010) causes it to decrepitate violently when heated in a closed tube, the mineral splitting along this direction. The lustre, moreover, is not sub-metallic as stated by Dana, but brilliantly metallic, the colour being, moreover, bronze, due perhaps to a superficial tarnish

[1] Mineralogy of India, p. 59, (1887).

[2] *Rec. Geol. Sur. Ind.*, XXXIII, p. 232, (1906).

Since the foregoing paragraph was written I have been able to visit the manganese-ore deposits at Rámandrug and Kamátaru in the Sandur Hills, and find this supposed manganite myself. It occurs in drusy cavities in the ore-bodies, and may occur in either wad or psilomelane. Specimens can be found showing every gradation between the hard bronzy-lustred mineral mentioned above, and a shining black mineral of exactly the same radiate character, but as soft as pyrolusite, which it then undoubtedly is. Of the specimens sent by Mr. Aubert some of the harder bronzy-lustred mineral was separated from the associated ores and the specific gravity of a piece weighing 2·19 grammes found to be 4·470. This being only slightly higher than the value of this constant for the unaltered manganite, which is 4·2–4·4, it was thought that analysis would show this piece to be nearly fresh manganite. The analysis was undertaken by Mr. C. Fawcitt of Shimoga with the following result :-

Chemical composition.

MnO_2	92·90
MnO	1·47
Fe_2O_3 and Al_2O_3 (mostly Al_2O_3)	1·88
CaO	0·86
MgO	0·52
SiO_2	0·47
Combined water	1·94
	100·04

From this analysis it will be seen that — in spite of the fact that in physical characters the mineral presents considerable differences from pyrolusite, and considerable resemblances to manganite — chemically the mineral is not far removed from pyrolusite. It is true that it still retains nearly 2 per cent. out of the original 10 per cent. of combined water it must have once contained, whilst there is still a small quantity of manganese protoxide remaining. Hence we arrive at the dilemma that this mineral, which was once almost certainly manganite, retains to a considerable extent the physical characters of manganite, but has been almost completely converted into pyrolusite, as far as chemical composition goes. As it would be most inconvenient to call this mineral pyrolusite, owing to its different physical appearance, and inaccurate to call it manganite, I propose to refer to it as *pseudo-manganite*. It must be remembered that the above analysis represents only one piece of the mineral. It is possible that if several

Pseudo-manganite.

analyses were made of different pieces some of them would be found to approach much closer to manganite in composition.

Specimens from Mysore and Goa.

Since describing the first of the Sandur specimens referred to above I have been able to examine a considerable number of specimens of manganese-ores obtained from Shimoga and Goa. These ores usually consist of psilomelane or pyrolusite, either separate or associated with one another, and are often cavernous. Sometimes the cavities are lined with mammillations of psilomelane; sometimes with crystalline growths of pyrolusite that may have once been manganite; and more rarely with needle-like aggregates, of superior hardness to pyrolusite possessing a steel-grey metallic lustre, that are probably to be regarded as either manganite or pseudo-manganite. Judging from specimens sent by Mr. C. Fawcitt from the Shimoga district, pseudo-manganite is probably present in the ores of both Kumsi and Bikonhalli.

One of the specimens from Bikonhalli consists of limonite with the cavities lined with psilomelane; this is frequently coated with a growth of stumpy crystals, probably of manganite or pseudo-manganite, on which the chief form visible is a prism, probably (110); the prisms have a tendency to be united to one another so as to form stellate groups. Specimens collected by Mr. H. D. Coggan in South Goa frequently show nests of what is in all probability manganite (or pseudo-manganite). The localities from which specimens containing this manganite have been obtained are Villian, Kajri Dongar, and Kumári, about 16 miles south of Sanvordem railway station. Specimens of manganese-ores from Puseli in the North Kanara district also often show this supposed manganite. It is not known whether these North Kanara ores are in true laterite or whether they have been formed by the replacement of the outcrops of Dhárwár rock (lateritoid).

On account of the ease with which manganite suffers alteration with the production of pyrolusite, and the fact that in the course of this alteration the manganite often acquires a black streak and looses a large portion of its water long before it has completely passed into pyrolusite, it is often a matter of extreme difficulty to decide whether to call a particular specimen manganite or pyrolusite, and it is to meet this difficulty that I have proposed the name pseudo-manganite for the examples occupying, both chemically and physically, the interval between manganite and pyrolusite. In the following table I give the characters

that may be made use of in referring a specimen of one of these minerals to its proper position, in the absence of a quantitative analysis :—

TABLE 9.

Comparison of properties of manganite, pseudo-manganite, and pyrolusite.

	Manganite.	Pseudo-manganite.	Pyrolusite.
Formula	$Mn_2O_3.H_2O$.	$xMnO. + yMnO_2 + zH_2O$	MnO_2.
Hardness	4	2·5—4	2—2·5
Specific gravity . . .	4·2—4·4	4·4—4·7	4·7—4·9
Streak	Reddish brown to nearly black.	Black.	Black.
Heated in a closed tube . .	Gives off water	Gives off a little water.	Often gives off a little water.

CHAPTER IV.

MINERALOGY—*continued.*

Manganates and Carbonates.

Hollandite—Psilomelane—Beldongrite—Wad—Ankerite—Rhodochrosite.

Hollandite.

This mineral was first brought to my notice by Mr. H. J. Winch at the time of my visit to the Kájlidongri deposit. On examination, I found that the mineral was probably a new one very similar to one I had found at Sitapár in the Chhindwára district. Mr. Winch kindly made a quantitative analysis of it showing that it was a manganate of barium, manganese, and iron.[1] Having decided that it was a new mineral I called it *hollandite* after Dr. T. H. Holland, Director of the Geological Survey of India, and published a preliminary description of it in the *Transactions of the Mining and Geological Institute of India*, Vol. I, page 76, (1906). Since then I have not been able to do any further work on the mineral and thus settle various points that need clearing up, such as its crystallographic system.

Occurrence.

At Kájlidongri the mineral occurs in the crystalline form in quartz veins traversing the manganese-ore deposit. It also sometimes passes into the manganese-ore of the ore-body, which is mainly psilomelane in the parts of the deposit where the hollandite occurs. What is in all probability a variety of the same mineral is found at Sitapár in the Chhindwára district, where it occurs as a constituent of the ores, being associated with sitaparite, braunite, pyrolusite, manganchlorite ?, and an arsenate ; Sitapár is the only locality at which I have found arsenates besides Kájlidongri. At the latter place the arsenates are not directly associated with the hollandite, so that this occurrence of arsenates and manganates at each of these places may be a purely fortuitous one. Crystalline manganates occur at a few other localities also, associated with the manganese-ores. They have not been definitely isolated and analysed, so that it is not certain how closely they approximate

[1] T. H. Holland, *Rec. Geol. Surv. Ind.*, XXXIII, page 98, (1906).

to the composition of the typical hollandite of Kájlidongri. Until more work has been done on these minerals I propose to use the name hollandite to include all the Indian crystalline manganates, though later on it may be found convenient to use the term in a more restricted sense. The other localities at which crystalline manganates occur are Gowári Warhona in the Chhindwára district; Mándvi Bir, Junawáni, and Junapáni, in the Nágpur district; and the Bálághát deposit in the district of that name: it is probable that crystalline manganates will be found to be of much more common occurrence than would be suspected from the fact that up till now they have never been recorded as occurring in the natural condition. Wherever a specimen shows psilomelane passing into a crystalline mineral—such as is commonly seen in the Sandur Hills and Mysore—one must be prepared for the possibility that the crystalline mineral may be hollandite, although as a rule it will probably be found to be pyrolusite or manganite. With the latter mineral in particular it is very liable to be confounded, especially when the manganite occurs in stumpy crystals. But, as will be seen from the account of the properties of hollandite given below, it is easy to distinguish the two minerals if pieces of any size can be obtained. The chief points of difference are the higher specific gravity and, when crystal faces can be used for the test, the superior hardness of the hollandite. A chemical test would also show that the mineral was hollandite if a strong reaction for barium were obtained; but with regard to this latter test it must be noticed that although all the crystalline manganates hitherto found contain a considerable proportion of baryta, yet it does not follow that a crystalline manganate will not be found practically free from this constituent.[1] It might also be thought that the presence of water of crystallization in manganite might be used as a criterion in distinguishing these two minerals. It must be remembered, however, that the Indian manganites are almost always in a state of partial dehydration owing to an incipient conversion into pyrolusite, with the result that they often give only a weak reaction for water when heated in a closed tube; whilst the crystalline manganates, like the amorphous ones grouped under the term psilomelane, may contain water in the form of hydrogen in the base portion of the mineral. As an example of the confusion that may arise between these two minerals, I may mention that many of the Shimoga manganese-ores contain pseudo-manganite as a lining

[1] Such as a crystalline form of the American fibrous lead-manganese manganate coronadite (see page 96).

to cavities. In most cases the difficulty is only one of determining whether the mineral is to be called manganite or pyrolusite; but in a few cases, when the crystals are small, or when they pass into more or less massive crystalline material too hard for manganite, it is necessary to recognise the possibility that hollandite may be present; this point can only be definitely settled by isolating some of the mineral and taking its specific gravity, and then, if this be not sufficient, making a chemical analysis of it.

Physical characters.

In colour hollandite varies from a light almost silvery grey through greyish-black to quite black. On both crystal faces and fracture surfaces it has a shining metallic lustre. In the Kájlidongri specimens, the only ones that exhibit definite crystal faces, the hardness is found to be 6 on the crystal faces and only 4 on the fracture surfaces. Owing to the infrequency of crystal faces the hardness test must as a rule be made on fracture surfaces, and therefore the latter figure may be taken as the more general value for the hardness of the mineral. This difference of hardness on the crystal and fracture surfaces is probably due to the fact that whilst the crystal faces are often smooth the fracture surfaces are almost invariably very much striated, so that testing the hardness on a fracture surface consists not in testing the real hardness of the mineral, but in tearing away the fibres of the mineral one from another; consequently the hardness found by testing the crystal faces must be taken as the true one. As this value is 6, it will be seen that this brings the mineral into line, as far as this property goes, with the hard varieties of the amorphous manganates grouped as psilomelane. The way in which hollandite splits into prismatic chips very much striated on every fracture in a direction parallel to the vertical crystallographic axis of the mineral is one of its most characteristic properties, although, of course, when the mineral does not occur in definite crystals it is not evident that the direction of splitting is this axis. The streak of the mineral is black.

Crystallographic characters.

The crystals that occur in the quartz-veins at Kájlidongri are sometimes of large size. Since my visit Mr. Winch has kindly collected considerable quantities of this mineral as it became exposed in the course of quarrying the ore. A common size for the crystals is a diameter of $\frac{1}{8}$ to $\frac{1}{2}$ inch, but some of the specimens obtained by Mr. Winch are as large as 1 inch across. In their simplest form the crystals show what looks like a tetragonal prism surmounted by a flat tetragonal

pyramid ; but the few angular measurements I have yet been able to make indicate that the mineral is either orthorhombic or triclinic, more probably the latter, and in either case very closely approaching the tetragonal form. The striations on the prism faces and the dullness of the pyramid faces have up to the present prevented this question being settled.

Fibrous hollandite.

There occurs at Kájlidongri a fibrous mineral that shows a beautiful silky lustre. Chemical work on this mineral indicates that it is fibrous variety of hollandite ; it is probable that the fibres are parallel to the vertical axis of the mineral, this being the direction of the fibrous striation seen on the fracture surfaces of crystals of hollandite. The manganate found at Sitapár occurs in prismatic individuals mixed with various other minerals, which prevent the manganate from developing true crystal faces. But it shows a prismatic development, the rough prisms being sometimes as long as one inch. At Gowári Warhona, the mineral is found in certain layers in the manganese-ore in the form of brilliant crystalline interlocking aggregates, the prisms being usually about $\frac{1}{16}$ to $\frac{1}{4}$ inch in length. This mineral must also be present in the ores of Mándvi Bir, Junawáni, and Junapáni. For the complete analysis of a piece from Junawáni indicates that the ore is a mixture of braunite and a manganate, the latter being present in this particular specimen in the proportion of 66 per cent. The manganate must be either crystalline or non-crystalline. In the latter case the mineral would be psilomelane, which would be easily visible as a dull matrix cementing the granules of braunite. But, since the whole piece of ore is crystalline, the manganate must be in the crystalline form ; that is it must be hollandite. In the same way the physical aspect of the ores of Mohugáon, Páli, and Ghogara, in the Nágpur district, taken in conjunction with such partial chemical analyses of them as have been made, shows that they also contain, in all probability, a crystalline manganate. At all the localities for this mineral in the Nágpur district the ores are in crystalline limestones. At Bálághát I collected one specimen of manganese-ore showing a veinlet about $\frac{1}{4}$ inch thick of a fibrous silky-looking mineral that at once suggested hollandite. That this is hollandite I have little doubt ; for the analysis (No. 1146, page 95) that has been made of a picked specimen of a very common type of crystalline ore in this

Hollandite in the Chhindwára district.

Hollandite in the ores found in the crystalline limestones, Nágpur district

Massive hollandite, Bálághát district.

deposit has shown it to be a manganate, which must b classed under hollandite. This type of ore is very fine-grained and seems to be crystalline throughout. It can be scratched with moderate ease with a knife and has a brilliant light-grey metallic appearance, so that in the sun it glistens almost like burnished silver, although the colour is somewhat darker than that of this metal. By comparison it was found that the nearest approach to its colour could be obtained by looking at a piece of aluminium in ordinary diffused light. This colour corresponds very closely to that of the ore as seen in the sun, although as seen in the shade alongside the aluminium the manganese-ore appears considerably darker. This ore occurs in very large quantities in this deposit, so that many thousand of tons of it must have been exported, hence, even from the commercial point of view, hollandite is, in India at least, an important mineral. This massive fine-grained variety of crystalline manganate occurs in beds of considerable thickness and extent, and one may often see, exposed in the quarry, a surface of this ore, many square feet in area, the whole of which exhibits the brilliant appearance noticed above. There is also in this deposit a large quantity of the uncrystallized manganate, psilomelane; in fact more of it than of the crystalline manganate.

Chemical composition.

The first analysis of hollandite was made by Mr. H. J. Winch on a specimen having a specific gravity of 4·95, and is shown below :—

Manganese peroxide (MnO_2) . .	65·63
Manganese protoxide (MnO) . .	5·12
Ferric oxide (Fe_2O_3) . . .	10·56
Alumina (Al_2O_3)	0·94
Baryta (BaO)	17·59
Silica (SiO_2)	traces
	99·84

This analysis corresponds to the following formula :—

$$m(Ba,Mn)_2MnO_5 + n(Fe,Al)_4(MnO_5)_3.$$

or $$m(Ba,Mn)_2MnO_5 + n(Fe_4(MnO_5)_3,$$

according as the alumina be considered an essential constituent or not.[1]

[1] Mr. T. R. Blyth, Assistant Curator, Geological Survey of India, has examined this mineral more carefully than was possible to Mr. Winch in his rough jungle laboratory and finds that it contains, in addition to the constituents found by Mr. Winch, small amounts of lime and magnesia and of one of the rarer elements, which has not been yet identified.

The precipitate obtained in Group II on passing H_2S has been examined spectroscopically by Prof. Noel Hartley and found to consist chiefly—in addition to sulphur—of barium sulphate and titania. Subsequently Dr. Morris Travers examined some of the original mineral and found that the H_2S precipitate contains traces of second-group elements to the extent of one part in 7,000. A careful analysis of the mixed sulphides showed them to consist principally of antimony with traces of arsenic, bismuth, and copper, the last two in exceedingly minute quantities.

Of the hollandite of other localities the only one of which an analysis is available is the massive variety of the Bálághát mine. On pages 797 and 971, however, analyses are given of picked pieces of ore consisting in the main of mixtures of braunite and a crystalline manganate. These analyses are recalculated into terms of their mineral composition, showing the manganates as composed of a series of manganates of the various base radicles of the mineral. The figures for the composition of the manganate as given on those pages I have converted to a total of 100, so that from these analyses of composite specimens it has been found possible to extract analyses of the crystalline manganate or hollandite.

These analyses, together with the analysis of the massive hollandite from Bálághát, are given below :—

TABLE 10.

Analyses of hollandite.

	Bálághát.	Gowári Warhona.	Junawáni.
Number of Specimen.	1146	752[1]	1062[1]
Manganese peroxide (MnO_2)	75·05	71·25	72·44
Manganese protoxide (MnO)	9·02	14·20	9·09
Ferric oxide (Fe_2O_3)	4·43	5·73	9·26
Alumina (Al_2O_3)	1·04	0·42	1·09
Baryta (BaO)	2·96	7·22	5·55
Lime (CaO)	0·31	0·38	2·50
Magnesia (MgO)	0·36	0·35	..
Potash (K_2O)	3·31	..	..
Soda (Na_2O)	0·57	..	..
Combined silica (SiO_2)	1·30	..	..
Free silica (SiO_2)	0·10	..	..
Sulphur	0·021	..	..
Phosphoric oxide (P_2O_5)	0·046	..	..
Arsenic oxide (As_2O_5)	*nil*	..	..
Cobaltous oxide (CoO)	0·05	..	..
Nickelous oxide (NiO)	*nil*	..	..
Cupric oxide (CuO)	trace	..	..
Lead oxide (PbO)	*nil*	..	..
Zinc oxide (ZnO)	trace	..	..
Titanic oxide (TiO_2)	0·03	..	..
Chlorine and fluorine	*nil*	..	..
Combined water (H_2O)	1·10	0·45	0·07
Moisture at 100°C.	0·15	..	..
Carbonic oxide (CO_2)	*nil*	..	..
	99·847	100·00	100·00
Manganese	54·42	56·04	52·83
Iron	3·10	4·01	6·48
Silica (total)	1·40	..	..
Phosphorus	0·02	..	..

[1] Since these calculations were made the following additional constituents have been determined at the Imperial Institute :—

	752	1062
NiO, Co_3O_4, CuO	0·011*	0·048†
K_2O	0·22	0·33
Na_2O	0·23	0·32

* Chiefly cobalt.
† Chiefly nickel.
Thsee would of course correspond to small quantities of manganates.

In terms of the different manganates these analyses can be re-stated as follows :—

TABLE 11.

Analyses of hollandite in terms of manganates.

	Bálághát.	Gowári Warhona.	Junawáni.
	1146	752	1062
$Fe_4(MnO_5)_3$	8·71	11·26	18·20
$Al_4(MnO_5)_3$	2·61	1·12	2·74
Ba_2MnO_5	3·95	9·63	7·41
Ca_2MnO_5	0·59	0·74	4·80
Mg_2MnO_5	0·82	0·79	..
K_4MnO_5	5·12	..	..
Na_4MnO_5	1·04	..	..
Co_2MnO_5	0·08	..	..
H_4MnO_5	3·96	1·74	0·23
Mn_2MnO_5	70·71	74·72	66·62
	97·59	100·00	100·00
Surplus oxygen	0·61		
SiO_2	1·40		
S	0·021		
P_2O_5	0·046		
TiO_2	0·03		
Moisture at 100°C.	0·15		
	99·847		

For comparison I have re-stated the analysis (given on page 91) of the typical hollandite in terms of its constituent manganates :—

$Fe_4(MnO_5)_3$	20·76
$Al_4(MnO_5)_3$	2·36
Ba_2MnO_5	23·50
Mn_2MnO_5	53·59
	100·21
Oxygen assumed	0·37
	99·84

It should be noticed that in calculating the mineral composition of composite specimens of ore from their analysis, a difference is usually found between the amount of oxygen determined and that required for the manganates left over after the braunite has been extracted from the analysis. This difference is, however, never sufficient to point to the presence of some other compound rather than manganates corresponding to the theoretical acid H_4MnO_5 ; in fact the errors are always sufficiently small to be attributable to experimental errors in their determination. The differences between the amounts of oxygen required for the manganates in the above analyses and the amounts actually found are as follows :—

	per cent.
Kájlidongri	—0·37
Bálághát	+0·61
Gowári Warhona	+0·85
Junawáni	—0·52

These differences may, as already stated, be due to experimental errors in the determination of the oxygen, but the discrepancies can be explained in another way. In the cases where there is a surplus of oxygen it may be that a portion of the manganese forming the basic radicle of the manganates is not in the protoxide form corresponding to the formula Mn_2MnO_5, but is in the sesquioxide form corresponding with the formula $Mn_4(MnO_5)_3$. The conversion of the requisite amount of Mn_2MnO_5 into $Mn_4(MnO_5)_3$ would account for this surplus oxygen. In the same way when there is a deficit in the amount of oxygen according to the above way of representing the mineralogical composition of the ores, this deficit can be accounted for by the conversion of an equivalent amount of ferric manganate, $Fe_4(MnO_5)_3$, into the ferrous manganate, Fe_2MnO_5. This point must for the present remain open to doubt ; but it is to be noticed that in the case of some of the analyses of psilomelane the discrepancy is perhaps too great to be attributable to experimental errors.

From the foregoing paragraphs it follows that the composition of these crystalline manganates can be represented by the general formulæ given below, in which the constituents are placed in order of importance in their respective brackets :—

$$m\,(Mn,Ba,K_2,H_2,Ca,Mg,Fe,Co)_2MnO_5 + n(Fe,Al,Mn)_4(MnO_5)_3.$$

This is, of course, the most general formula, but it can be simplified, by omitting the least important constituents, as follows :—

$$m\,(Mn.Ba,K_2.H_2)_2MnO_5 + n\,(Fe,Al)_4(MnO_5)_3.$$

In any particular case a more definite formula can, of course, be given. Thus the three analyses given above correspond roughly to the following formulæ :—

Bálághát	$m(Mn,Ba,K_2,H_2)_2MnO_5 + n(Fe,Al)_4(MnO_5)_3$.
Gowári Warhona	$m(Mn,Ba)_2MnO_5 + nFe_4(MnO_5)_3$.
Junawáni	$m(Mn,Ba,Ca)_2MnO_5 + n(Fe,Al)_4(MnO_5)_3$.

As will be seen from these formulæ these manganates correspond to the hypothetical acid H_4MnO_5, and it seems as if there is a whole series of compounds derived from this acid by isomorphous replacement. Laspeyres [1] has already suggested that psilomelane may conform to this formula, and we see that the existence of compounds corresponding to this formula is put beyond doubt by the discovery of the definitely crystallized minerals here described. As will be shown under the heading of psilomelane this latter mineral also conforms to the formula suggested by Laspeyres, at least as far as can be judged from a large number of analyses of Indian psilomelanes. Hence it seems probable that hollandite is to be regarded as the crystalline form of psilomelane, there being no essential difference in chemical composition between the two minerals. An interesting problem for future solution is to find out what determines whether the mineral takes the crystalline or amorphous form, and why it is that crystalline manganates, which are by no means uncommon in India, are not found wherever psilomelane occurs in all parts of the world.[2] It is interesting to note that W. Lindgren and W. F. Hillebrand [*Amer. Jour. Sci.*, XVIII, pp. 448-460, (1904)] describe a new mineral from Arizona under the name of *coronadite*. They regard their analysis as indicating the mineral to be a salt of a derivative of ortho-manganous acid, $H_2Mn_3O_7$. I find, however, that their analysis corresponds very closely with R_2MnO_5, where R = Mn and Pb chiefly. The mineral is fibrous, and

Coronadite.

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1 *Jour. für prak. Chemie*, XIII, p. 215, (1876) [Dana].

2 It is interesting to note that M. Al. Gorgeu in a paper called 'Sur les oxydes de manganèse naturels', *Bull. de la Soc. fr. de Mineralogique*, III, (1890), says, on page 22, that the interior of a specimen of psilomelane from Romanèche, in Saône et Loire, France, was crystalline. He gives analyses of both the exterior non-crystalline portion, and interior crystalline portion. He calculates out formulæ for these specimens, and also for specimens of psilomelane from Thuringia in Germany, and Lorsa in Spain, according to which psilomelanes are hydrated manganites with 'bases multiples et variées'. I find, however, that both the Romanèche analyses can be converted into a series of manganates of the form R_2MnO_5, the oxygen errors, however, being rather large, namely deficits of 1·44 and 1·00; but these would have been less had I taken account of the arsenic oxide of which amounts of 1·50 and 0·70 % are shown in the two analyses, and converted it into arsenates. I think it is probable that this crystalline psilomelane is identical with hollandite. The non-crystalline and crystalline portions contain 16·20 and 14·45 per cent. of BaO, respectively.

hence corresponds to the fibrous variety of hollandite. At present I see nothing that certainly shows the reason of the formation of crystalline manganates at one time and non-crystalline ones at others. An examination of the analyses of hollandite shows, however, that the crystalline manganates always contain a fair quantity of barium and iron; this may indicate that the manganates can only assume the crystalline form in the presence of fair quantities of these two elements, although the number of analyses available is not really sufficient to base such a general statement upon. Such a hypothesis would explain why ores low in these constituents were found as psilomelane and not as hollandite, but it would not explain the case of varieties of psilomelane containing as large quantities of iron and barium as hollandite. Hence it seems more probable that the reason for the formation of crystalline manganates at one time and non-crystalline ones at others is to be looked for in the conditions of formation rather than in the chemical composition of the manganates.

Specific gravity.

As might be expected, the great variability in the composition of the manganates from different localities is accompanied by a corresponding variability in the specific gravity of these minerals. Thus a picked specimen of this mineral from Sitapár in the Chhindwára district was found to have a specific gravity of only 4·70, whilst the specimen analysed by Mr. Winch from Kájlidongri had a value of 4·95 for this constant. Determinations of the specific gravity of several other picked specimens from this locality have given values ranging from 4·93 to 4·99. The massive specimen of hollandite of which the analysis is given on page 93, had a specific gravity of only 4·59, this low value being in all probability due to the fact that the specimen was an aggregate and not a piece of a separate crystal. It should be noticed, however, that these values for the specific gravity correspond roughly with the differences in the amounts of baryta present in each specimen, the values of this constituent in the Kájlidongri, Sitapár and Bálághát specimens being 17·59, 6·20. and 2·96, respectively.

Psilomelane.

Occurrence.

Of all the manganese-ores found in India, this is the most abundant; with braunite it makes up by far the larger proportion, probably at least 90 per cent., of the manganese-ores exported from India. Its existence in India was apparently first recognized by A. J. Scott in association with

the braunite of the Vizagapatam district[1]. As this mineral occurs at almost every locality where manganese-ores are found in India there is no point in enumerating all the different occurrences of it. An account of all those recognized up to 1887 will be found in Mallet's Mineralogy, page 61. In addition to the localities mentioned by Mallet many others have, of course, since been recognized and a reference to these can be obtained from the index to this Memoir. In the Nágpur-Bálághát area of the Central Provinces, in Jhábua, Nárukot, and the Panch Maháls, the psilomelane often forms an intimate mixture with braunite, which occurs scattered throughout in small granules to which the psilomelane acts as a cement. (See Plate 1.) With increasing quantities of braunite, or of psilomelane, there is a gradual passage into ore which is practically all braunite on the one hand and all psilomelane on the other. In the Vizagapatam district, also, the ores often consist of psilomelane containing scattered braunite; but in this case the braunite patches are often larger than is customary in the Central Provinces, whilst they are less abundant. In fact ore consisting of psilomelane free from braunite is very common in this district, whilst in the Nágpur-Bálághát area of the Central Provinces it is comparatively rare, Guguldoho, Bálághát, and Ukua, being the only notable localities. In the other areas where this mineral is found in quantity it is not associated with braunite, except perhaps occasionally in minute quantities, but occurs either alone or in association with pyrolusite. The more important of such areas are the following;—Belgaum, Goa, Jabalpur, Mysore, Sandur Hills, Sátára, and Singhbhum.

Physical characters.

According to Dana's System of Mineralogy, page 257, 6th Edition, psilomelane exhibits the following characters:— It occurs either massive, or in botryoidal, reniform, or stalactitic shapes. G = 3·7—4·7; Hardness = 5—6, *i.e.*, it can sometimes be scratched by a knife and at other times cannot. Lustre submetallic, dull. Streak brownish black, shining. Colour, iron-black, passing into dark steel-grey. Opaque.

The Indian psilomelanes agree fairly well with the above diagnosis.

Form.

The best example of massive psilomelane is probably that of the Bálághát deposit in the Central Provinces, where this mineral forms massive beds alternating with layers of quartzite and of massive hollandite. Botryoidal shapes, that is, those stimulating more or less closely a bunch of grapes in shape, are perhaps best exemplified in some of the ores found in the Sátára district,

[1] *Edin. New Phil. Jour.*, LIII, p. 278, (1852).

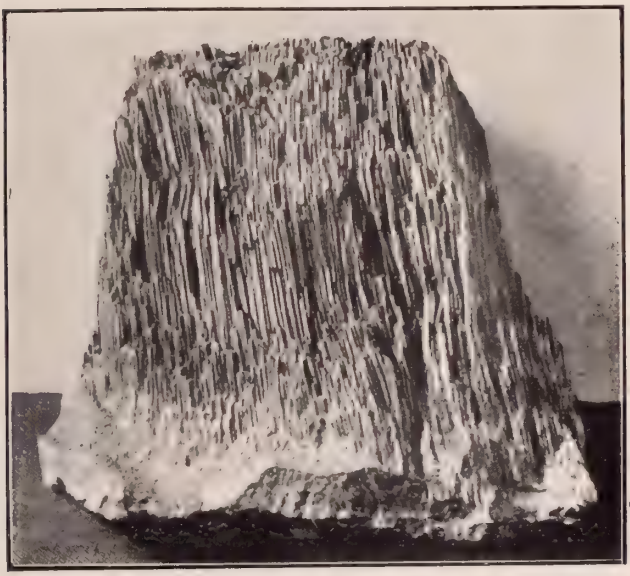
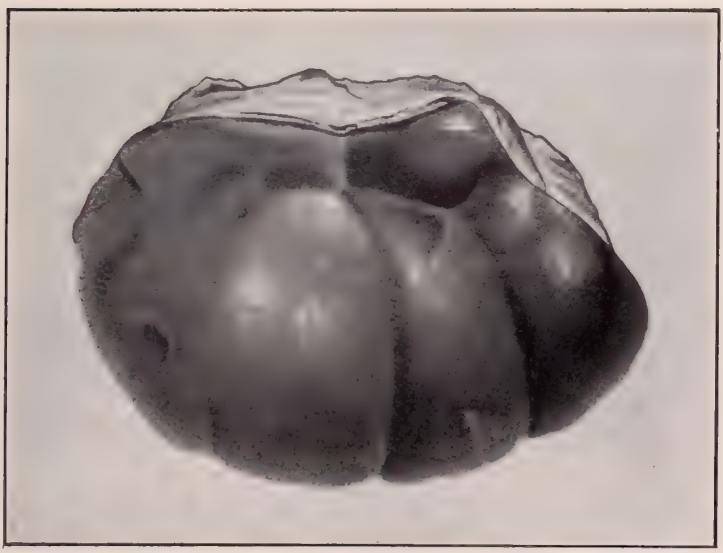


Photo. by H. B. W. Garrick.

Fig. 1.—STALACTITIC PSILOMELANE FROM GARBHAM, VIZAGAPATAM DISTRICT, MADRAS. ½ NATURAL SIZE.



From a Sepia Sketch. *Calcutta Phototype Co.*

Fig. 2.—RENIFORM PSILOMELANE FROM GARBHÁM, VIZAGAPATAM DISTRICT, MADRAS. ½ NATURAL SIZE.

Photo. by H. B. W. Garrick.

Fig. 1.—PSILOMELANE SHOWING CONCHOIDAL FRACTURE, TEKRASAI, SINGHBHUM DISTRICT, BENGAL (J. 917). FULL SIZE.

Calcutta Phototype Co.

Fig. 2.—MAMMILLATED PSILOMELANE FROM GUGULDOHO, NĀGPUR DISTRICT, C. P. ½ NATURAL SIZE.

especially at Yeruli. The best example of this mineral I have seen showing a reniform shape is a specimen found loose at Garbhám in the Vizagapatam district (see fig. 2, Plate 5). At Guguldoho I found a very fine specimen of psilomelane with a form that can be best described as liver-shaped or hepatiform. The specimen as first found was some 10 inches across and resembled nothing so much in shape as the liver of one of the large carnivora, such as a panther. It was made up of concentric layers and is the specimen No. 1157 of which an analysis is given on page 100. At this locality is to be found almost every variety of concretionary structure exhibited by psilomelane, there being many fine examples of mammillary forms. Fig. 2, Plate 6, shows one of these. The best example of stalactitic psilomelane I have seen from India was found by Mr. Geeson at Garbhám in the Vizagapatam district (see fig. 1, Plate 5). According to Dana the lustre varies from submetallic to dull. This applies to most of the Indian psilomelanes, but there is one variety, found at Garbhám and Ávagudem in the Vizagapatam district, and at Kumsi and other deposits in Mysore, that on fresh fracture resembles very closely in colour and lustre a piece of metallic lead, so that its lustre can be described as metallic. This is the variety of which an analysis is given on page 100 (No. A. 372). The streak of this mineral is said by Dana to be brownish-black in colour. Although this undoubtedly holds for some examples, yet the Indian psilomelanes have, as often as not, a black streak. In colour the Indian specimens vary from iron-black through dark steel-grey to an almost bluish-grey, this bluish tint being especially noticeable when one is collecting specimens in the blazing sunlight of an Indian dry-weather day.

Specific gravity.

It will be noticed that the specific gravity of the specimens of which analyses are given on page 100 all lie between the limits given by Dana. They tend, however, to be almost invariably over 4 in value, the only exception being the lead-like variety.

Composition.

I have already mentioned in discussing the composition of hollandite, which is to be regarded as the crystalline form of this mineral, that analyses of both minerals conform very closely to the formula first suggested by Laspeyres, so that both psilomelane and hollandite can be regarded as derived from a hypothetical acid of the composition H_4MnO_5. Below I give a series of five analyses carried out by Messrs. J. and H. S. Pattinson of Newcastle-on-Tyne on specimens collected by myself. For the purposes of analysis I picked out pieces that were as homogeneous as could be

found, carefully took their specific gravities, and sent to the analysts the whole of the specimen in the powdered condition. Guguldoho is in the Nágpur district, Central Provinces ; Ávagudem in the Vizagapatam district, Madras ; and Tekrasai in the Singhbhum district, Bengal.

TABLE 12.

Analyses of Indian psilomelanes.

	Guguldoho.	Ávagudem.	Tekrasai.	Tekrasai.	Tekrasai.
Number of Specimen.	1157	A. 372	A. 380	A. 381	J. 917
Manganese peroxide (MnO_2)	83·13	73·35	70·78	79·87	82·44
Manganese protoxide (MnO)	6·37	3·61	7·63	6·61	6·47
Ferric oxide (Fe_2O_3) . .	1·50	5·71	0·21	0·07	0·50
Alumina (Al_2O_3) . .	0·15	3·55	0·30	0·75	0·45
Baryta (BaO) . . .	0·03	2·43	15·08	5·16	2·07
Lime (CaO) . . .	0·21	0·54	0·08	0·29	0·47
Magnesia (MgO) . .	0·18	0·25	0·25	0·22	0·16
Potash (K_2O) . . .	3·10	3·25	0·20	2·33	2·63
Soda (Na_2O) . . .	0·45	0·02	0·15	0·18	0·18
Combined Silica (SiO_2) .	0·25	0·45	0·05	0·05	0·10
Free Silica (SiO_2) . .	*nil*	*nil*	*nil*	*nil*	*nil*
Sulphur	0·021	0·034	0·039	0·037	0·025
Phosphoric oxide (P_2O_5) .	0·838	0·791	0·737	0·676	0·696
Arsenic oxide (As_2O_5) .	0·003	*nil*	*nil*	*nil*	*nil*
Cobaltous oxide (CoO) .	0·1	0·15	0·25	0·20	0·35
Nickelous oxide (NiO) .	*nil*	*nil*	0·20	0·15	0·05
Cupric oxide (CuO) . .	0·002	0·04	0·08	0·04	0·01
Lead oxide (PbO) . .	*nil*	*nil*	*nil*	*nil*	*nil*
Zinc oxide (ZnO) . .	*nil*	0·15	0·30	0·40	0·55
Titanic oxide (TiO_2). .	0·01	trace	*nil*	*nil*	*nil*
Chlorine	*nil*	*nil*	trace	trace	*nil*
Fluorine	*nil*	*nil*	*nil*	*nil*	*nil*
Combined water (H_2O) .	3·40	3·80	3·30	2·60	2·65
Moisture at 100°C. . .	0·25	2·05	0·45	0·45	0·35
Carbon dioxide (CO_2) .	*nil*	*nil*	*nil*	*nil*	*nil*
	99·994	100·175	100·086	100·083	100·151
Manganese . . .	57·78	49·18	50·66	55·61	57·14
Iron	1·05	4·00	0·15	0·05	0·35
Silica (total) . . .	0·25	0·45	0·05	0·05	0·10
Phosphorus . . .	0·366	0·346	0·322	0·295	0·304
Specific gravity . .	4·26	3·86	4·54	4·41	4·38

It is noticeable what a large percentage of P_2O_5 is present in all these specimens of psilomelane. The quantity is in fact so large that the amount of CaO present is not nearly sufficient for the phosphoric oxide to be present as apatite. It is not known therefore in what form the P_2O_5 is present is the mineral. I can only suggest that it forms a phosphate with some other base than the lime, possibly a manganese phosphate. In the absence of any knowledge on this point I have been compelled to disregard this constituent in considering these analyses. In the same way the small amounts of sulphur, possibly present as barytes, and the minute quantities of TiO_2, and of As_2O_5, have been neglected; whilst, in view of the small amount returned (0·05 to 0·45 per cent.), I have not made any allowance for the combined silica; that is, I have not used it to form a corresponding amount of braunite, especially as no such second mineral is evident in the specimens. Leaving these constituents out of consideration, therefore, the foregoing analyses can be arranged in terms of manganates as follows:—

TABLE 13.

Analyses of Indian psilomelanes in terms of manganates.

	Guguldoho.	Ávagudem.	Tekrasai.	Tekrasai.	Tekrasai
	1157	A. 372	A. 380	A. 381	J. 917
$Fe_4(MnO_5)_3$	2·95	11·22	0·41	0·14	0·98
$Al_4(MnO_5)_3$	0·38	8·92	0·75	1·88	1·13
Ba_2MnO_5	0·04	3·25	20·14	6·89	2·76
Ca_2MnO_5	0·40	1·04	0·15	0·56	0·90
Mg_2MnO_5	0·41	0·57	0·57	0·50	0·36
K_4MnO_5	4·79	5·02	0·31	3·60	4·07
Na_4MnO_5	0·82	0·04	0·27	0·33	0·33
Co_2MnO_5	0·17	0·25	0·42	0·34	0·59
Ni_2MnO_5	..	..	0·34	0·25	0·08
Cu_2MnO_5	..	0·07	0·13	0·07	0·02
Zn_2MnO_5	..	0·24	0·49	0·65	0·90
H_4MnO_5	13·12	14·66	12·73	10·03	10·22
Mn_2MnO_5	74·74	52·90	62·28	72·39	75·12
	97·82	98·18	98·99	97·63	97·46

TABLE 13—(*contd.*).

Analyses of Indian psilomelanes in terms of manganates.

	Guguldoho.	Ávagudem.	Tekrasai.	Tekrasai.	Tekrasai.
	1157	A. 372	A. 380	A. 381	J. 917
Carried forward . .	97·82	98·18	98·99	97·63	97·46
SiO_2	0·25	0·45	0·05	0·05	0·10
Sulphur	0·021	0·034	0·039	0·037	0·025
P_2O_5	0·838	0·791	0·737	0·676	0·696
As_2O_5	0·003	..	...	..	..
CuO	0·002	..	..	..	..
TiO_2	0·01	..	..	..	..
Moisture at 100°C . .	0·25	2·05	0·45	0·45	0·35
	99·194	101·505	100·266	98·843	98·631
Surplus oxygen . .	0·80	..	..	1·24	1·52
Oxygen assumed . .	..	1·33	0·18	..	..
	99·994	100·175	100·086	100·083	100·151

It will be seen that on the assumption that these specimens have the respective compositions given above there is a considerable error in the oxygen determination. But, as in the analyses of hollandite, these differences can be explained on the assumption that in the case of an excess of oxygen a corresponding portion of the manganese is in the form, not of manganous manganate, Mn_2MnO_5, as shown above, but of manganic manganate, $Mn_4(MnO_5)_3$; whilst in the case of a deficit the difference can be explained on the hypothesis that a portion of the iron is in the form of ferrous manganate, Fe_2MnO_5, instead of ferric manganate, $Fe_4(MnO_5)_3$, as represented. To show what difference this would make I will take the cases of the analyses in columns 2 and 5, where there is a deficit of 1·33 of oxygen in one case and an excess of 1·52 of oxygen in the other. In the former case the oxygen can be obtained from the ferric manganate in accordance with the following equation :—

$$3Fe_4(MnO_5)_3 = 6Fe_2MnO_5 + Mn_2MnO_5 + 10\ O;$$

according to this equation the deficit of 1·33 of oxygen could be obviated by the conversion of 15·69% $Fe_4(MnO_5)_3$ into 12·32% Fe_2MnO_5 + 2·04% Mn_2MnO_5 + 1·33 % of oxygen. The only difficulty in the way of accepting this interpretation is the fact that there is

not so much ferric manganate available to be converted into ferrous and manganous manganates and oxygen. Still the difference, namely 4·47 of ferric manganate, only corresponds to an oxygen error of 0·38. In the case of the excess of 1·52 of oxygen, this excess can be used to convert manganous manganate into manganic manganate according to the following equation :—

$$7Mn_2MnO_5 + 10\ O = 3Mn_4(MnO_5)_3;$$

according to this equation 1·52 of oxygen converts 16·29 of Mn_2MnO_5 into 17·81 of $Mn_4(MnO_5)_3$.

In analyses 1157 and A. 381 the surplus oxygen is enough to convert 8·57 and 13·29 of Mn_2MnO_5 into 9·37 and 14·51 of $Mn_4(MnO_5)_3$, respectively. Making these alterations, the five analyses can be rewritten as follows, leaving the two in which there is an oxygen deficit unaltered and omitting all the constituents that do not come into the manganate molecules :—

	Guguldoho.	Ávagudem.	Tekrasai.	Tekrasai.	Tekrasai.
	1157	A. 372	A. 380	A. 381	J. 917
$Fe_4(MnO_5)_3$	2·95	11·22	0·41	0·14	0·98
$Al_4(MnO_5)_3$	0·38	8·92	0·75	1·88	1·13
$Mn_4(MnO_5)_3$	9·37	..	..	14·53	17·81
Ba_2MnO_5	0·04	3·25	20·14	6·89	2·76
Ca_2MnO_5	0·40	1·04	0·15	0·56	0·90
Mg_2MnO_5	0·41	0·57	0·57	0·50	0·36
K_4MnO_5	4·79	5·02	0·31	3·60	4·07
Na_4MnO_5	0·82	0·04	0·27	0·33	0·33
Co_2MnO_5	0·17	0·25	0·42	0·34	0·59
Ni_2MnO_5	..	..	0·34	0·25	0·08
Cu_2MnO_5	..	0·07	0·13	0·07	0·02
Zn_2MnO_5	..	0·24	0·49	0·65	0·90
H_4MnO_5	13·12	14·66	12·73	10·03	10·22
Mn_2MnO_5	66·17	52·90	62·28	59·10	58·85
	98·62	98·18	98·99	98·87	98·98

If now we want to find out the molecular ratio of manganates of the general formula R''_2MnO_5 (*i.e.* all the manganates above, except the ferric, manganic, and aluminic manganates), to the manganates of the general formula $R'''_4(MnO_5)_3$ (*i.e.*, the ferric, manganic, and aluminic manganates), then the simplest way is to take the sum of the quantities of the group

MnO_3 combined with each manganate of the general formula R''_2MnO_5, and divide by $\frac{1}{3}$ of the sum of the quantities combined with the manganates of the general formula $R'''_4(MnO_5)_3$, nearly all these quantities being obtained in the course of calculating the original analysis into terms of manganates. These figures work out as follows for each specimen :—

	Amounts of MnO_3 in manganates of the type R''_2MnO_5.	Amounts of MnO_3 in manganates of the type $R'''_4(MnO_5)_3$.	Figures in second column divided by 3	Molecular ratio of the group R''_2MnO_5 to the group $R'''_4(MnO_5)_3$.
Guguldoho-1157 . . .	40·10	6·31	2·10	19·1
Avagudem-A. 372 . .	36·75	10·88	3·63	10·1
Tekrasai-A. 380 . . .	41·84	0·65	0·22	144·7
Tekrasai-A. 381 . . .	36·49	8·37	2·79	13·1
Tekrasai-J. 917 . . .	35·84	9·96	3·32	10·8

Taking the general formula of psilomelane as $mR''_2MnO_5 + nR'''_4(MnO_5)_3$ it is seen that, if n be unity in each case, the value of m in the foregoing examples varies from about 10 to 145, but is usually between 10 and 20.

Rammelsberg, in his Handbuch der Mineralchemie, page 182, (1860), regards psilomelane as a combination of potash, baryta, and protoxide of manganese, with peroxide of manganese, corresponding to the formula $(Mn,Ba.K_2)O.(MnO_2)_2$. In the second edition of his Handbuch der Mineralchemie, pages 189-192, (1875), [Penrose], he divides psilomelanes into two varieties, namely baryta-psilomelane and potash-psilomelane, according to whether the mineral is high in baryta or potash. Dana in his System of Mineralogy, 6th edition, page 257, says that psilomelane is a 'hydrous manganese manganate in which part of the manganese is often replaced by barium or potassium, perhaps conforming to H_4MnO_5', giving Laspeyres[1] as the authority for this formula, and adding that the material analysed is generally impure, so that the composition is doubtful. The specimens analysed above were apparently pure specimens, so that the results of their analysis can be taken as giving the correct composition. The above calculations show that this mineral does conform to the formula H_4MnO_5, and that the chief constituents of the basic portion of the mineral, in addition to manganese and hydrogen, are either barium or potassium, although in one case (A. 372) considerable amounts of iron and

[1] *Jour. für. prak. Chemie*, XIII, p. 215, (1876).

aluminium enter into the composition of the manganate[1]. It will be noticed, however, that these specimens cannot be conveniently divided into baryta-psilomelanes and potash-psilomelanes. Thus 1157 can be called a potash-psilomelane and A. 380 a baryta-psilomelane, but the other three all contain moderate proportions of both constituents.

The general formula

$$mR''_2MnO_5 + nR'''_4(MnO_5)_3,$$

to which reference was made above, can be expressed. so as to show the constituents corresponding to R″ and R‴, in the following comprehensive way :—

$$m[(Mn,H_2,Ba,K_2,Ca,Mg,Na_2,Zn,Co,Ni,Cu)_2MnO_5] + n[(Mn,Fe,Al)_4(MnO_5)_3].$$

Omitting the less important constituents in each case, the composition of the five specimens can be stated as follows :—

Guguldoho (1157)	$19[(Mn,H_2,K_2)_2MnO_5]$	+	$(Mn,Fe)_4(MnO_5)_3$.
Avagudem (A. 372)	$10[(Mn,H_2,K_2,Ba)_2MnO_5]$	+	$(Fe,Al)_4(MnO_5)_3$.
Tekrasai (A. 380)	$145[(Mn,Ba,H_2)_2MnO_5]$	+	$(Al,Fe)_4(MnO_5)_3$.
Tekrasai (A. 381)	$13[(Mn,H_2,Ba,K_2)_2MnO_5]$	+	$(Mn,Al)_4(MnO_5)_3$.
Tekrasai (J. 917)	$11[(Mn,H_2,K_2,Ba)_2MnO_5]$	+	$Mn_4(MnO_5)_3$.

In these formulæ I have placed the elements constituting the basic radicles in the order of their importance considered from the point of view of the amount of manganate they form by combination of their oxides with the requisite amounts of MnO_3.

If R be entirely Mn, then the formula of the mineral becomes Mn_2MnO_5 or Mn_3O_5, which would contain 67·35% Mn and 32·65% O. At least two observers have previously suggested the existence of this compound in nature. In one case J. A. Jones[2] gives an analysis of a 'cryptocrystalline' mineral from Covadanga in Northern Spain, which he thinks corresponds fairly closely to $2MnO_2.MnO$ ($=Mn_3O_5$). A calculation of his analysis shows, however, an oxygen deficit of 2·81%, if an attempt be made to convert it into

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1 I have already noted—footnote on page 96—that M. Gorgeu deduces from his analyses of specimens of psilomelane that psilomelanes are hydrous manganites, but that his analyses of two specimens from Romanèche conform closely to manganates of the general formula R_2MnO_5 He gives the formula corresponding to the Lorca analysis as $6(MnO_2)\,RO.{}_2H_2O$, He regards this, like the other formulæ given, as a hydrated manganite. The deficiency of the base portion of this formula, as of the others given, is noticeable ; whilst it is interesting to note that the formula given for the Lorca analyses can be re-arranged as follows :—

$$6(MnO_2).RO.2H_2O = RO.2H_2O.3MnO.3MnO_3$$
$$= 6RO.3MnO_3$$
$$= 3R_2MnO_3$$

in which there is no deficit or surplus of either basic or acid radicle.

2 *Trans. Inst. Min. Met*, III, p. 276, (1894-95).

manganates. An ore described by E. G. Williams[1] from Soledad in Panama in Central America, as massive and like psilomelane, was analysed by W. E. Ford in Prof. Penfield's laboratory. Penfield says the ore agrees well with the composition $MnO.2MnO_2$ or Mn_3O_5, and may be a new mineral species. A conversion of the analysis given into manganates shows that it agrees very well with the formula R''_2MnO_5, the oxygen error being a deficit of 0·34%.

Description of specimens.

I will now give a brief description of the specimens of which the analyses are given on page 98. Each specimen was broken into two, one piece used for analysis and the other kept for reference.

1157.—Guguldoho.

This piece was a portion of the hepatiform concretion mentioned on page 99. I did not find it *in situ*, but obtained it from a stack of quarried ore. The piece selected for analysis was broken from a concentric shell about ¾ inch in thickness. It shows a finely concentric structure parallel to the exterior of the shell, the bands being so fine as to impart to the specimen a somewhat satiny lustre. In grain it is extremely fine and in colour a rather light steel-grey, with a bluish tint in the sun. The colour of its streak is brownish black. Its hardness is just over 6, and the specific gravity of the piece analysed 4·26, the closeness of the texture of the specimen being well exemplified by the fact that it did not exhibit any noticeable porosity when left to soak in water. The outer and inner coats of the specimen were covered with a thin brownish skin exhibiting a few minute micaceous scales, but this skin was completely removed before the specific gravity was taken. The fracture is beautifully conchoidal.

A. 372.—Ávagudem.

This specimen was selected from the stacks of ore at this mine. This type of ore is rather cavernous and contains both ferruginous patches and soft black patches. After a little trouble, however, some 6 grammes of the mineral free from these blemishes were obtained ready for analysis. This variety has the appearance of slightly tarnished metallic lead, its colour being just a little darker, but its lustre very similar. It appears absolutely homogeneous, and has a brownish black streak. The fracture

[1] *Trans. Amer. Inst. Min. En.*, XXXIII, pp. 203, 204, (1902).

is beautifully conchoidal. The hardness is 6·5, and the specific gravity, determined on the above 6 grammes, 3·85, the mineral exhibiting no appreciable porosity.

A. 380.—Tekrasai.

This specimen I extracted from *in situ* in a pit at Tekrasai in the Singhbhum district, Bengal, the ore being only about 2 feet below the surface of the ground. In colour it is a dark bluish grey, the lustre being quite dull except for a few scattered specks that suggest the possible existence in the ore of a small quantity of the crystalline manganate, hollandite. In structure the ore is minutely pisolitic, on account of which there are often, between the separate concretions, minute cavities, which sometimes contain a dark brownish black powder, and sometimes are empty. The proportion of material different to the main mass of the ore, which may be described as a dull dark grey variety of psilomelane, is, however, very small and will not have affected the analysis to any large extent. In consequence of this structure, however, the ore is markedly porous, and in taking its specific gravity some day's soaking were found to be necessary before the weight in water became constant[1]. The specific gravity was found to be 4·54. The hardness of the specimen is just under 6, and the fracture fairly even, but not conchoidal, the texture not being of the requisite fineness for this. The streak is nearly dead black, there being a slight brown tinge.

A. 381.—Tekrasai.

This specimen was found *in situ* in the same pit as the preceding one. It is the most fine-grained variety I have yet seen, having more the texture of porcelain than of anything else. It is not, however, hard, but is easily scratched by fluorite and has a hardness of about 3; one of the most interesting features about it is the fact that its fracture surfaces are covered with a sort of black bloom that soils the fingers in the same way as the bloom on a plum does. When this bloom is on, the colour can best be described as a dull iron-black, with perhaps just a tinge of brown. If, however, this bloom be rubbed off with the finger, as it easily can be, the mineral is seen to be a shining iron-black with perhaps a tinge of brown in it. The lustre is perhaps best described as resinous, when the

[1] In all cases the specimens were afterwards dried by putting them outside on the top of an airbath so as to remove, before powdering for analysis, the water absorbed during the determination of the specific gravity.

bloom has been removed, being dull before this is done. The streak of this variety is deep brownish black in colour ; its specific gravity is 4·41, the mineral, in spite of its close texture being porous, and thus requiring some 3 days soaking before its weight in water becomes constant. The fracture is beautifully conchoidal.

J. 917.—Tekrasai.

This specimen was obtained *in situ* from a different pit to the two preceding. It is also of extremely fine grain, exhibiting beautiful conchoidal structure, the colour being a deep blue-grey, whilst in the sun the fracture surface shows iridescent reflections. The streak is brownish black in colour, the hardness about 5, and the specific gravity 4·38, the specimen being non-porous (see Plate 6, fig. 1).

Calculation of analyses of braunite-psilomelane ores.

Scattered throughout the descriptive portion of this Memoir will be found several complete analyses of hand-specimens of manganese-ores composed of mixtures of braunite and psilomelane. It is possible to make use of these analyses for the extraction of further analyses of psilomelane. Before giving a list of such analyses I will give an example of the way in which such an analysis can be re-calculated into terms of its mineral composition. A good example to take will be the analysis given on page 656 of specimen No. A. 607 from Sivarájpur in the Panch Mahál district of the Bombay Presidency. The specific gravity of this specimen is 4·25 and inspection of it indicates that it consists of numerous tiny grains of braunite in a matrix of psilomelane. In calculating the mineral composition the P_2O_5 is first taken out as *apatite* in the following way, no allowance being made for the requisite chlorine or fluorine (these are stated to be absent ; but the quantity required for the apatite is so small that it would probably be overlooked in the course of analysis) :—

0·366 P_2O_5 require $0·368 \times 1·312 = 0·48$ CaO, leaving $1·32 - 0·48 = 0·84$ CaO, and yielding 0·846 of apatite.

The *combined silica* is next made use of to form *braunite*, the formula of this mineral being assumed to be $3Mn_2O_3.MnSiO_3$, since this formula is usually found to agree with the analyses very well.

For braunite 4·20 SiO_2 require

$$4·20 \times \frac{78·29}{9·98} = 32·95\ Mn_2O_3$$

and

$$4·20 \times \frac{11·73}{9·98} = 4·94\ MnO.$$

It is usually found to be convenient to assume that the Fe_2O_3 present in the ore replaces an equivalent amount of Mn_2O_3 in the braunite, although it may also often be regarded as forming ferric manganate, $Fe_4(MnO_5)_3$, and has been so regarded in some of the analyses scattered through the text. Now 6·00 Fe_2O_3 is equivalent to 5·92 Mn_2O_3, so that for the braunite above only 32·95 — 5·92 of Mn_2O_3 is required; the composition of the braunite is therefore as follows :—

Mn_2O_3	27·03
Fe_2O_3	6·00
MnO	4·94
SiO_2	4·20
	42·17

Now	27·03 Mn_2O_3	=	18·82	manganese	+ 8·21	oxygen.
and	4·94 MnO	=	3·82	„	+ 1·12	„
totalling			22·64	„	+ 9·33	„
Available in analysis			51·40	„	+ 26·03	„
∴ remaining for psilomelane			28·76	„	+ 16·70	„

For the formation of psilomelane :—

1·19 Al_2O_3	require	1·80 MnO_3,	giving	2·99	$Al_4(MnO_5)_3$
0·79 BaO	„	0·27 „	„	1·06	Ba_2MnO_5
0·84 CaO	„	0·77 „	„	1·61	Ca_2MnO_5
0·94 MgO	„	1·20 „	„	2·14	Mg_2MnO_5
2·27 K_2O	„	1·24 „	„	3·51	K_4MnO_5
0·23 Na_2O	„	0·19 „	„	0·42	Na_4MnO_5
0·02 CuO	„	0·01 „	„	0·03	Cu_2MnO_5
0·05 ZnO	„	0·03 „	„	0·08	Zn_2MnO_5
2·00 H_2O	„	5·71 „	„	7·71	H_4MnO_5
		11·22 MnO_3	„	19·55	manganates

11·22 MnO_3	=	5·99 Mn	+	5·23 O
Available	=	28·76 Mn	+	16·70 O
Left	=	22·77 Mn	+	11·47 O

To form Mn_2MnO_5, 22·77 Mn require
11·04 oxygen, yielding . . . . . 33·81 Mn_2MnO_5

giving total of psilomelane as . . . . . 53·36
and leaving a surplus of 0·43 oxygen unused.

This analysis can therefore be rewritten in the following way :—

Apatite		0·846
Braunite		42·17
Psilomelane		
$Al_4(MnO_5)_3$	2·99	
Ba_2MnO_5	1·06	
Ca_2MnO_5	1·61	
Mg_2MnO_5	2·14	
K_4MnO_5	3·51	
Na_4MnO_5	0·42	
Cu_2MnO_5	0·03	
Zn_2MnO_5	0·08	
H_4MnO_5	7·71	
Mn_2MnO_5	33·81	
	53·36	53·36
Quartz (free silica)		2·70
Sulphur		0·021
TiO_2		0·04
Moisture at 100° C.		0·60
Oxygen unused		0·43
		100·167

Calculated analyses of psilomelane.

Now by taking the above psilomelane and reducing the whole to 100 we obtain an analysis of this mineral expressed in terms of manganates; and by a re-grouping of the constituents of the manganates in terms of oxides we obtain an analysis in the usual form. One defect of analyses of psilomelane so extracted from analyses of mixed specimens of ore is that in extracting the braunite all the iron oxide is often assumed to replace Mn_2O_3 in the braunite, leaving none for the psilomelane. On examining the analyses of psilomelane given on page 112, it will be seen that, although this mineral often contains but a small quantity of ferric oxide, yet, on the other hand, it sometimes contains a considerable quantity of this constituent. Unfortunately there is often no means of telling in any particular case whether the iron present is in the braunite or in the psilomelane. An other draw-back to this method of extracting analyses of psilomelane is the fact that, as shown under the heading of braunite, the composition of braunite is not a constant one, but usually corresponds to one of three formulæ, namely :—

(1) $3Mn_2O_3.MnSiO_3$; (2) $7Mn_2O_3.2MnSiO_3$; (3) $4Mn_2O_3.MnSiO_3$

and there is usually no means of telling which to employ in any particular case. As already mentioned, however, I have assumed the first of these formulæ in making these calculations ; in the first place because when I first made them I had not discovered that the formula of braunite does

not always conform to the formula given in Dana's System of Mineralogy, namely $3Mn_2O_3.MnSiO_3$; and in the second place because the difference between the amount of oxygen required with this method of calculation and that actually found is usually not very large. In cases where this error is large, say over 1%, then it might be found that the assumption of one of the other formulæ for braunite would reduce the difference between the oxygen required and that actually found. But, as in the case of the analyses of specimens of pure psilomelane given on the preceding pages, this difference can be more easily accounted for by assuming a portion of the manganese to be in the form of manganic manganate instead of manganous manganate, in the case of an excess of oxygen; or by assuming a portion of the iron to be in the form of ferrous manganate instead of ferric manganate, in the case of an oxygen deficit. In the following table are given 12 analyses of psilomelane extracted, in the manner explained above, from the analyses of specimens of manganese-ore scattered through the descriptive portion of this work. In these no attempt has been made to allow for the oxygen difference, but all the iron has been entered up as ferric manganate and all the basic manganese as manganous manganate.

TABLE 14.

Analyses (in terms of manganates) of psilomelane obtained by calculation.

	M.3	995	1017	1037	1074	1089	M.4	A.467	A.505	A.520	A.607	60
	Kodegáon.	Kándri.[1]	Parsoda.[1]	Mansar.[1]	Beldongri.[1]	Lohdongri.[1]	Sontulai.	Kájlidongri.	Kájlidongri.	Kájlidongri.	Sivarájpur.	Bálághát.[1]
$Fe_4(MnO_5)_3$	18·71	..	..	..	11·93	..	12·73	..	..	..	..	17·41
$Al_4(MnO_5)_3$	7·48	1·10	2·04	3·66	1·39	0·25	2·27	3·64	3·04	5·57	5·61	6·34
$Mn_4(MnO_5)_3$	..	..	..	..	..	..	..	..	..	..	..	..
Ba_2MnO_5	0·22	..	1·36	4·53	1·09	3·55	2·88	17·62	14·23	4·25	1·99	6·05
Ca_2MnO_5	..	1·84	6·09	3·85	3·49	4·18	..	4·33	2·43	8·62	3·02	0·41
Mg_2MnO_5	..	2·11	1·49	0·68	1·61	4·18	..	4·83	2·80	9·82	3·99	1·84
K_4MnO_5	..	..	..	..	..	..	..	1·17	2·14	0·48	6·58	..
Na_4MnO_5	..	..	..	..	..	..	..	0·67	0·31	0·30	0·79	..
Co_2MnO_5	2·57	..	..	..	..	..	0·94	..	..	1·50	..	..
Ni_2MnO_5		..	..	..	..	..	2·07	..	..	..	..	..
Cu_2MnO_5	..	..	..	..	..	..	2·49	0·15	0·05	0·18	0·05	..
Zn_2MnO_5	..	..	..	..	..	..	..	0·35	0·14	0·48	0·15	..
H_4MnO_5	13·45	13·45	34·61	19·84	21·01	9·54	10·97	8·36	8·56	25·39	14·45	6·02
Mn_2MnO_5	57·57	81·50	54·41	67·44	59·48	78·30	65·65	58·88	66·30	43·41	63·37	61·93
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

[1] Since these calculations were made, the following additional constituents have been determined at the Imperial Institute :—

	995	1017	1037	1074	1089	60
NiO, Co_3O_4 and CuO	0·028	0·030	0·020*	0·020	0·032	*nil*
K_2O	0·14	0·04	0·10	0·12	0·14	0·14
Na_2O	0·42	0·18	0·16	0·25	0·17	0·45

They would not affect the above analyses seriously.

* Chiefly cobalt.

In the second table (No. 15) I give the analyses of the same psilomelanes arranged in terms of their oxides. On examining these analyses it will be seen that there is occasionally a small surplus of oxygen over that required for the conversion of all the manganese present into peroxide. This, of course, means that in these particular cases the amount of manganese in the form of MnO_3 in the manganates is in excess of the amount of manganese in the form of MnO in the base portion of the molecule, Mn_2MnO_5. I am not aware, however, that such an excess of oxygen over that required to convert all the manganese present in a mineral into peroxide has ever been recorded. Probably it is not to be expected except in the case of a mixture of two minerals, one of which in course of formation probably rejects oxygen from MnO_2, taking only the MnO portion, and thus liberates a surplus of oxygen for the remaining mineral, the psilomelane. In this case the braunite perhaps acts in this way.

It will be further seen from these analyses that these examples of psilomelane are very variable in composition, apart from the question of whether iron is shown as present or not, this being, as already explained, to a large extent due to whether the iron has been calculated into the braunite or the psilomelane of the original analysis. In several of the analyses the alkalies have not been determined, but cannot be large in amount in these cases, because in the original analyses the totals approximated to 100 without them.[1] Only one of them shows an important amount of potash. This is the Sivarájpur specimen. The baryta is variable in amount, being in one case *nil* and in two of the Kájlidongri specimens as high as 10·66 and 13·22% respectively. The latter figure is not surprising in view of the fact that the hollandite of this locality contains 18% of this constituent. In several of the analyses cobalt, nickel, copper, and zinc, have not been looked for.[2] But in those in which these constituents were tested for, namely the first and the last five, variable amounts of these constituents were found. Thus in one case, namely M.4 from Sontulai, which might perhaps be better included under the heading of wad than in this place, there is 1·52% of copper oxide, CuO. The nickel oxide, NiO, is as high as 1·23% in the same specimen, whilst in one of the Kájlidongri specimens there is 0·90% of cobalt oxide, CoO.

1 These have since been determined; see footnote to table on page 112.

2 The Co, Ni, and Cu, have since been determined; see footnote to table on page 112

TABLE 15

Analyses of psilomelane obtained by calculation.

	M.3	995	1017	1037	1074	1089	60	M.4	A.467	A.505	A.520	A.607
	Kodegáon.	Kándri.	Parsoda.	Mansar.	Beldongri.	Lohdongri.	Bálághát.	Sontulai.	Kájlidongri.	Kájlidongri.	Kájlidongri.	Sivarájpur.
MnO_2	82·25	79·25	84·12	82·12	84·56	76·44	77·05	78·10	73·14	73·19	74·93	80·32
MnO	..	14·93	..	5·60	..	14·30	4·46	6·19	4·23	8·55	..	4·06
Oxygen	0·09	..	1·26	..	0·02	..	..	..	..	..	2·50	..
Fe_2O_3	9·51	..	..	..	6·07	..	8·87	6·47	..	..	..	..
Al_2O_3	2·98	0·44	0·81	1·46	0·56	0·10	2·51	0·91	1·45	1·22	2·22	2·23
BaO	0·16	..	1·02	3·39	0·81	2·66	4·53	2·17	13·22	10·66	3·17	1·48
CaO	..	0·96	3·17	2·00	1·82	2·19	0·21	..	2·25	1·27	4·49	1·58
MgO	..	0·93	0·65	0·30	0·71	1·84	0·81	..	2·12	1·20	4·31	1·76
K_2O	..	..	..	..	..	..	..	..	0·76	1·39	0·30	4·26
Na_2O	..	..	..	..	..	..	..	..	0·37	0·17	0·18	0·43
CoO	1·52	..	..	..	..	..	..	0·55	..	..	0·90	..
NiO								1·23	..	..	..	..
CuO	..	..	..	..	..	..	..	1·52	0·08	0·04	0·12	0·04
ZnO	..	..	..	..	..	..	..	..	0·22	0·09	0·30	0·09
H_2O	3·49	3·49	8·97	5·13	5·45	2·47	1·56	2·86	2·16	2·22	6·58	3·75
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Manganese	52·00	61·66	53·18	56·25	53·46	59·39	52·16	54·16	49·51	52·89	47·37	53·91
Available oxygen	15·21	14·58	16·73	15·20	15·57	14·05	14·17	14·37	13·45	13·46	16·28	14·77

Beldongrite.

At Beldongri, on the north side of the pit, there is a variety of manganese-ore, havin a smooth shiny fracture and the colour and lustre of pitch. It is somewhat like the specimen of psilomelane, A. 372, from Ávagudem in the Vizagapatam district, of which an analysis is given on page 100 ; but is more shiny in its lustre, and darker. A piece of this picked for analysis contained a little spessartite-garnet, which, on account of its intimate association with the pitch-like mineral, could not be completely removed. The latter in fact seems to have been derived from the garnet by some process of alteration. At Chárgáon in the same district, a similar substance forms a matrix to the unaltered spessartite, from which it in this case also seems to have been derived by alteration. The specific gravity of the specimen chosen was 3·22, whilst its hardness was 4. The analysis, carried out at the Imperial Institute, is given on page 968. In calculating this analysis into terms of its mineralogical composition, there is no alternative, since no braunite is visible, to taking out the small quantity of combined silica as spessartite, assumed to have the formula $3MnO.(Al,Fe)_2O_3.3SiO_2$. It is found that the remainder of the oxides cannot be combined to make manganates owing to a great deficiency in the amount of oxygen required for this purpose. The free silica must, of course, be regarded as present in the form of quartz. This must, however, be in a very finely divided condition as it is in no way visible in the specimen. The analysis can then be written as follows :—

Specimen No. 1079.

Apatite	0·12
Calcite	0·25
Spessartite	3·70
Mn_3O_5	58·50
Fe_2O_3	6·88
BaO	0·78
CaO	2·10
MgO	0·15
H_2O (combined)	6·16
Quartz	17·72
As_2O_5	0·005
Moisture	4·21
	100·575
Subtract oxygen assumed	0·82
	99·755

It is interesting that the manganese oxides returned in the original analysis, after using 1·28% for the spessartite, should turn out to be so nearly in the proportions required for Mn_3O_5, *i.e.* for Mn_2MnO_5, corresponding to psilomelane in which all the basic portion of the manganate is occupied by manganous manganese. If, now, we regard the BaO, CaO, and MgO, as impurities, and reduce the Mn_3O_5, Fe_2O_3, and H_2O, to molecular proportions, the following is the result :—

$$Mn_3O_5 = \frac{58\cdot50}{229} = \cdot2554 = 6 \times \cdot0426$$

$$Fe_2O_3 = \frac{6\cdot88}{160} = \cdot0430 = 1 \times \cdot0430$$

$$H_2O = \frac{6\cdot16}{18} = \cdot3422 = 8 \times \cdot0428$$

These proportions work out so exactly that it seems probable that they correspond to the definite formula :—

$$6Mn_3O_5.Fe_2O_3.8H_2O.$$

No analysis has been yet made of the apparently similar mineral occurring at Chárgáon, so that it is not known if there is really a definite mineral corresponding to the above formula. In order, however, to distinguish it, it will be well to give it a temporary name, and the best suited for the purpose is *beldongrite*, after the place where the mineral occurs. The mineral is, however, only to be regarded as a variety of psilomelane and is not easily to be distinguished from the lead-like varieties, such as the Avagudem specimen referred to above, except in its darker colour. It is to be understood that this is only a provisional name, which it may be necessary to discard in the future, if it be found that other specimens of apparently similar material do not correspond to this formula. The actual specimen is to be regarded as a mixture of beldongrite (71·54%) with 17·72% of quartz and 3·70% of spessartite.

Wad.

Characters.

According to Dana, in his System of Mineralogy, 6th edition, page 258, the term wad includes a number of mineral substances, such as bog-manganese, asbolite, and lampadite, that are not to be regarded as distinct mineral species, but rather as mixtures of various oxides, chiefly of manganese (MnO_2 also MnO), cobalt, copper, with also iron, and from 10 to 20 p. c. water

The characters as given by Dana are as follows :—

'In amorphous and reniform masses, either earthy or compact: also incrusting or as stains. Usually very soft, soiling the fingers: less often hard to H. =6. G. =3·0 - 4·26; often loosely aggregated, and feeling very light to the hand. Colour dull black, bluish or brownish black.'

There seems, however, to be every passage between psilomelane and wad, so that one often finds a specimen that one is doubtful whether to call psilomelane or wad.

In naming Indian specimens of manganese-ores, the practice I have followed with regard to the uncrystallized or amorphous ores is to designate all those as psilomelane that in any way exhibit the characters of that mineral, the hardness especially being a criterion. If the mineral be a soft one, and show a finely crystalline structure, I have relegated it to pyrolusite, whilst if it show no signs of crystalline structure nor of the compact, firm amorphous structure of psilomelane, I have called it wad, this term being thus reserved for the indefinite mixtures so often found in manganese-ore deposits[1].

Occurrence.

Some of the chief localities for wad are the various deposits in the Vizagapatam district, where this substance has often been formed in considerable quantities by the replacement of the lithomargic matter accompanying the ore deposits. Wad is also extremely abundant in association with the manganese-ore deposits of the Sandur Hills and Mysore State. In the Sandur Hills it is best exposed in the deposits being worked at Rámandrug. Here it is intimately associated with psilomelane, the two together forming a very considerable proportion of the ores extracted. It is evident from the mode of association of these two minerals that the wad is the first-formed mineral and that it subsequently gets converted into the psilomelane, probably on the advent of a further portion of manganese in solution. The wad itself tends to be tabular or laminated in form, owing to its having been formed by the replacement of original laminated rocks, probably slates or phyllites. In colour it is greyish black, giving a soap-like streak that varies in colour from deep chocolate through brownish black to nearly black. It is fairly compact, but very soft, and usually preserves the original slaty or phyllitic structure of the rock that

[1] M. Gorgeu, in his paper 'Sur les oxydes de manganèse naturels'. *Bull. de la Soc. fr. de Minéralogique*, III. pp. 25—28, (1880), regards wads or 'manganèse liège' as true manganites, acid and hydrated, and conforming in certain cases to the formulæ :—

$3(MnO_2)RO.H_2O$ and $3(MnO_2)RO.3H_2O$.

He also says that wads are sometimes crystalline.

it has in all probability replaced. Wad also occurs in the lithomargic rocks associated with the manganese-ore deposits at Rámandrug. In Mysore there is also a great abundance of wad associated with the manganese-ore deposits in each of the four districts of Chitaldrug, Kadur, Shimoga, and Tumkur. It usually occurs associated with lithomarges and ochres in the soft altered rocks underlying the manganese-ore deposits. It is usually very light in weight, and, as a rule, is very fine-grained and compact, with a tendency to possess the structure of compact lithomarge. In colour it varies from almost pure black through deep brownish black to the brown of an ochre, there being a passage from one to the other, corresponding no doubt to changes in the relative amounts of manganese and iron. The streak is similar to that of the Sandur wad. Passages from wad to psilomelane can often be seen in the Mysore deposits. Another example of what may be regarded as wad is the specimen, of which the analysis is given on page 114, from Sontulai in the Hoshangábád district, Central Provinces. Other examples are to be found amongst the lateritic ores in most parts of India. In many of the most compact ores of the Nágpur-Bálághát area, Central Provinces, cavities or cracks are often found containing a small quantity of a deep brown velvety powder, which is also probably to be included under the term wad.

Composition.

The following two analyses of wads from the Vizagapatam district were carried out by Messrs. J. & H. S. Pattinson of Newcastle-on-Tyne, on specimens carefully picked by myself so as to be as far as possible homogeneous. Owing to the soft and crumbly nature of the specimens it was not possible to take their specific gravity.

	Spec. No. A.221 Garbhám. Brown wad.	*Spec. No. A.333* Kodur, Black wad.
MnO_2	58·12	61·38
MnO	4·14	3·59
Fe_2O_3	7·79	5·86
Al_2O_3	3·15	2·91
BaO	3·29	9·53
CaO	0·82	1·32
MgO	0·61	0·54
K_2O	1·18	0·61
Na_2O	0·37	0·31
SiO_2 (combined)	7·85	3·00
SiO_2 (free)	3·10	0·40
Sulphur	0·016	0·048
P_2O_5	0·198	0·261
As_2O_5	0·026	0·012
CoO	0·15	0·16
NiO	*Nil*	0·10
CuO	0·01	0·05
PbO	*Nil*	*Nil*
ZnO	0·25	0·15
TiO_2	0·06	0·02
Chlorine and fluorine	*Nil*	*Nil*
Combined water (H_2O)	7·30	5·50
Moisture at 100° C.	1·55	4·35
CO_2	*Nil*	*Nil*
	99·980	100·041
Manganese (Mn)	39·95	41·59
Iron (Fe)	5·45	4·10
Silica (total)	10·95	3·40
Phosphorus (P)	0·086	0·114

It will be seen that both these analyses show a considerable proportion of combined silica. This, however, is not present in the form of braunite as is usually the case with Indian manganese-ores containing combined silica ; for the specimens appear to be homogeneous and certainly do not contain any visible crystalline constituent. Considering the mode of formation of these ores, namely by the replacement of lithomargic rock, or perhaps partly during the formation of the lithomarge from the original potash-felspar contained in the rocks associated with the manganese-ore deposits of this area, it seems probable that the combined silica is present

in the form of lithomarge or kaolin, and perhaps partly as potash-felspar only partially converted into kaolin. Taking the first analysis it is found that the composition can be represented as follows :—

Specimen No. A. 221.

Orthoclase	6·99
Albite	3·14
Kaolin	2·50
Apatite	0·458
Psilomelane	85·50
Quartz	3·10
Sulphur	0·016
As_2O_5	0·026
TiO_2	0·06
Moisture	1·55
	103·340
Oxygen assumed	3·36
	99·980

From the large amount of oxygen, namely 3·36, below that required for the formation of psilomelane, it follows that this wad is not a mixture of manganates (psilomelane) with the other constituents orthoclase, albite, kaolin, and quartz ; but that it is in all probability an indefinite mixture of oxides of manganese, iron, etc., with partly kaolinized felspar. In the same way the analysis of the Kodur wad can be calculated into a mixture of 6·43% of kaolin with psilomelane, the latter making up the bulk of the residue. But, as before, there is too large a deficit of oxygen, in this case 1·94%, so that this wad also is probably to be regarded as a mixture of oxides. On page 1090 is given an analysis of a specimen No. A. 228, collected at Garbhám, that seems to be physically intermediate between psilomelane and wad. It is very porous and has a specific gravity of 4·08. It contains scattered through it a fair quantity of tiny specks of a magnetic mineral, which is probably manganmagnetite. As is shown on that page, the analysis can be re-arranged so as to consist of 5·57% of kaolin, 10·45% of magnetite, and 82·21% of psilomelane, with no excess or deficit of oxygen. It is not certain, however, that this is the correct interpretation ; for the specimen may be only a mixture of oxides similar to the specimens noticed above. The chances, however, are in favour of its correctness, and it seems that this specimen is to be regarded as psilomelane just passing from the wad stage of indefinite mixtures. It is still soft, however ; but might have become harder later on by a more com-

plete incorporation of the manganates one with another. I have seen many examples of ores indicating that psilomelane may sometimes pass through the stage of loose aggregation characteristic of wad, and later become consolidated, perhaps through a more complete union of the oxides, with the formation of manganates. The characters of the two specimens of wad of which the analyses are given above are shown below.

A. 221.—*Garbhám.*

This ore is dark grey-brown, and is lithomargic in aspect, being fine-grained and fairly adherent when dry. It is very soft (H = about 1) and has a dark brown streak. It is dull, except for little patches having somewhat of the lustre of graphite and possibly consisting of stained kaolinic films.

A. 338.—*Kodur.*

This shows slickensided surfaces of a shining black colour. It some what resembles dirty coal, is more friable than A. 221, and has a nearly dead black streak. H = 1. Both this and the preceding are light in weight, but are too friable for the specific gravity to be determined.

Ankerite.

Ankerite is a sub-species of rhombohedral carbonate, intermediate in composition between calcite magnesite and siderite ; it has the chemical formula $CaCO_3$. $(Mg,Fe,Mn)CO_3$. As the formula shows, it also contains a small quantity of manganese. Amongst the serpentinous crystalline limestones exposed in a nála near Gowári Warhona in the Chhindwara district, and of which an example is described in a paper on the petrology of this part of the district[1], I found one, 17·68 in the rock-register showing reddish brown plates of a rhombohedral carbonate enclosing, in a poikilitic fashion, rounded grains of calcite. The dark carbonate gives a faint reaction for manganese, and hence is probably to be regarded as ankerite ; for it is doubtless also magnesian, since these serpentinous limestones almost invariably contain dolomite.

[1] *Rec. Geol. Sur. Ind.*, XXXIII, p. 202, (1906).

R. D. Oldham says[1] 'In the Tons below Anu there are exposures, of a brown ferruginous and dolomitic limestone, passing into crystalline ankerite in places which I have conjecturally correlated notwithstanding its lithological difference. with the Chakrata limestone.' The Chakrata limestone is one of the pre-cambrian formations of the Himálaya and is found in Jaunsar in the Dehra Dun district. The specimen (6·403) of this rock is of a general buffish colour with grey specks. Its G.= 2·75. Other specimens in the Geological Survey collection labelled as ankerite were collected by Mr. Oldham on the 'cart road below Sairi' (6·440), and in the 'Jumna valley about 3 miles above the bridge on the old Mussoorie road' (6·438 and 6·439). Both these places are in Jaunsar, the latter being in lat. 30° 33′, long. 78° 1[1]. The Jamna valley specimen is a fairly coarsely crystallized rock showing a rhombohedral carbonate of cream colour with a brownish tinge. The faces of the carbonate are often curved and exhibit a pearly lustre like that of dolomite. The rock contains a large number of small crystals of pyrite, often altering to limonite, and also shows brown bands, probably due to iron oxide. It has a specific gravity of 2·97 and reacts for manganese, iron, calcium and magnesium.

Rhodochrosite.

Although a rare mineral in India rhodochrosite is one of the minerals that, if found in quantity, constitute a valuable ore of manganese. It is a carbonate of manganese corresponding to the formula $MnCO_3$ with a theoretical percentage of manganese =47·83. The mineral is white, pink, or light brown, in colour, with a rather pearly lustre. Its streak is white. It is easily scratched by a knife (H=3·5 to 4·5), whilst it effervesces briskly with warm dilute hydrochloric acid, and is distinguished by this property, as well as by its inferior hardness, from rhodonite, which it otherwise resembles somewhat closely in external aspect. According to Dana G.=3·45 to 3·60 and higher. This ore has been extensively mined in the French Pyrenees and at a few other localities. Before it is charged into the smelting furnaces, however, it has to be roasted to remove the carbon dioxide, leaving an oxidized product intermediate in composition between MnO and Mn_3O_4, which would correspond, if the original ore were pure, to

Characters.

[1] *Rec. G. S. I.*, XVI, p. 194, (1883).

a percentage of metallic manganese lying between 77 and 72. Hence it will be seen that although the original ore, even if pure, is considerably lower in its manganese contents than the oxidized ores that make up the whole of the ore exported from India, yet it may contain after roasting a considerably higher manganese percentage than the oxide ores. If any large supplies of rhodochrosite or carbonate ores should ever be discovered in India, it would of course be advantageous to roast them before exporting, on account of the great saving in freight charges that would accrue.

Occurrence.

As already mentioned, this mineral is a rare one in India; it has up to date been found only in the Chhindwára and Nagpur districts, both of them in the Central Provinces. In the Chhindwára district rhodochrosite has been found at two localities, namely Gaimukh and Devi. At Gaimukh the rhodochrosite occurs in a rock composed of rhodonite and rhodochrosite with manganese-ore, the latter being probably braunite. The rhodochrosite is pale pink or pinkish white in colour, and occurs as small interstitial patches of pearly lustre between the rhodonite and braunite individuals, which form by far the larger portion of the rock. It also occurs in a rock composed of spessartite and rhodonite, but only in small quantity. At Devi it occurs sparingly as a rock composed of this mineral, with a larger proportion of rhodonite. Under the microscope it appears that rhodochrosite is not so quickly blackened to manganese oxides as rhodonite; but it does also suffer this oxy-alteration. The rhodochrosite is not as a rule clear as seen under the microscope; but is clouded, so that the cleavage is usually obscured. In one case where the cleavages were visible they were seen to be curved. In one case, also, signs of twinning were detected in spite of the clouding of the mineral; but as a rule rhodochrosite does not seem to exhibit this phenomenon. The other microscopic characters that the mineral exhibits are absorption and a high birefringence, which do not of course enable one to distinguish it from the other rhombohedral carbonates. Like dolomite it does not stain when treated with Lemberg's stain, at least as far as I have been able to ascertain on the clouded specimens I have been able to test. At Devi the amount of this mineral in the ore is inconsiderable, but at Gaimukh, when the ore-deposit is worked, it may be found that almost every piece of ore contains at least a small quantity of rhodochrosite. That this will not, however, be large in the aggregate, is shown by the analysis of a sample from this locality given on page 784, in which the amount of carbon dioxide is only 0·41%, corresponding to 1·07 of rhodochrosite. In several other of the analyses of manganese-

ores from the Central Provinces as carried out at the Imperial Institute, small quantities of carbon dioxide have been returned. In two cases, namely Pali (page 957) and Ghogara (page 964), the amounts of this constituent are larger than in the Gaimukh ore. This is, however, in all probability due to calcite and not to rhodochrosite ; for these ores occur in crystalline limestones. In the other cases, in most of which there is no indication of calcite in association with the ores, it may either mean that there is a very small proportion of rhodochrosite present, although this has not been detected in the ores of these places either macroscopically or microscopically or that carbon dioxide is in most cases really absent, the determination of its presence being due to experimental errors unavoidable when dealing with such small quantities of a substance so elusive as a gas.

The one occurrence of this mineral in the Nágpur district is a doubtful one ; this is at Pársioni, where it seems to occur very sparingly in some of the rocks of the gondite series. The rock in which it occurs is composed mainly of rhodonite and spessartite, with a certain amount of amphibole, and sometimes orthoclase. The carbonate is to be seen clearly in microscope sections only, where it is sometimes intergrown with rhodonite, and sometimes right in the middle of the spessartite.

CHAPTER V.

MINERALOGY—*continued.*

Silicates—Pyroxenes and Amphiboles.

Blanfordite—Manganhedenbergite—Schefferite (?) & urbanite (?)—Pyroxenes of Vizagapatam—Colourless pyroxenes—Jeffersonite—Rhodonite—Manganese amphiboles—Dannemorite (?)—Winchite—Juddite.

Manganese-bearing pyroxenes.

Amongst the manganese-bearing rocks in the Archæan areas of Vizagapatam, the Central Provinces, Jhábua, and Nárukot, pyroxenes containing a certain quantity of manganese are fairly common. There seem to be a considerable variety of such pyroxenes, owing no doubt to variations in the amounts of manganese and other constituents present: rhodonite is the species containing the most manganese, being manganese metasilicate; whilst most of the other varieties probably contain but very small quantities of manganese. Several of these are probably varieties new to science; but, in most cases, they have not yet been closely examined, except in so far as is necessary in the course of the microscopic examination of thin slices of the rocks in which they occur. Nevertheless, I will give below the little I have determined with regard to these pyroxenes.

Blanfordite.

The name of this variety has already been announced in a paper read before the Mining and Gelogical Institute of India, and I cannot do better than quote here what was published in the Transactions of this Institute[1]. The typical mineral was found in the Kácharwáhi quarry, Nágpur district. The account of this mineral given in the above-cited publication is as follows:-

The Kácharwáhi occurrence.

'It is notable for its striking and beautiful pleochroism, which even in thin sections is—

a=rose-pink,
b=bluish lilac,
c=sky-blue.

'In thick sections the a and b axis colours are deep carmine and very rich sky-blue respectively. When fresh, the pyroxene is deep crimson as seen in hand specimens, but it is often altered so as to be chocolate-brown in colour. The mineral is mono-

Original account.

[1] Vol. I, p. 78, (1906).

clinic, with a small angle of extinction. The crystals noted below show three forms, the prism, clino-pinacoid and clino-dome, and sometimes exhibit basal parting planes best seen in thin sections under the microscope. In sections at right angles to the acute bisecrix a figure can be obtained, but points of emergence of the optic axes lie outside the field of view of the microscope. The specific gravity (as determined with some minute fragments and Sonstadt's solution) is 3·15. Before the blowpipe the mineral fuses easily to a black bead, gives a marked sodium flame and with fluxes gives indications of small quantities of manganese and iron. It occurs partly as a pyroxene-braunite-rock with interstitial apatite, and partly in aggregates and scattered crystals up to an inch long in a rather coarsely crystalline albite-rock. I propose to call this mineral *blanfordite*, after the late Dr. W. T. Blanford.'

Since this was written I have been able to pay a second visit to this locality and obtain a further supply of the mineral. I have at present little to add to the above account, except that in some of the thin sections of the rocks containing blanfordite I have found an amphibole of somewhat similar pleochroism that is likely at first to be confounded with the pyroxene unless the considerably lower index of refraction of the amphibole be noticed, or a section be hit upon that shows the characteristic cleavages of the amphibole group (see juddite). Moreover, the albite-rock mentioned above frequently contains microcline and sometimes a little quartz. In figures 11 and 12 illustrations are given of two crystals of this mineral. Figure 11, showing the forms *m* (110), *b* (010), and *e* (011), represents the common habit of the mineral, the crystals of this habit ranging

Crystallographic characters.

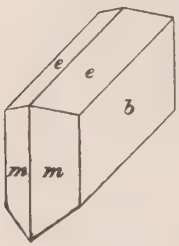

Fig. 11—Blanfordite.

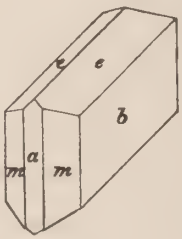

Fig. 12—Blanfordite.

from perhaps $\frac{1}{4}$ inch in diameter up to the size figured. Figure 12,

showing the extra face a (100), represents only one crystal, which is about 2 inches long in the direction of the $\breve{a}$ axis. With regard to the systematic position of this pyroxene it is at present impossible to speak with any certainty, since the mineral has not yet been analysed; but as it seems to have some resemblance to the pyroxene from St. Marcel known as violan, which has been shown by Penfield[1] to be a variety of diopside, it seems probable that blanfordite will also turn out to be related to diopside. In this same paper, on page 292, Penfield describes another pyroxene, which shows a very faint pleochroism in very pale rose and very pale blue. An analysis of this pyroxene shows 0·58% MnO and 1·06% Mn_2O_3 and Penfield considers the pyroxene to be composed of about equal parts of diopside, jadeite, and acmite, with 3·0% of the molecule $NaMn(SiO)_2$.

The Rámdongri occurrence.

What is probably blanfordite was also found at Rámdongri, also in the Nágpur district, where it occurs in the manganese-ore body in a patch of a rock that is probably to be regarded as a granitic intrusive. This rock, noticed on page 857, is of rather fine grain and is composed of microcline, quartz, plagioclase, and perhaps orthoclase with some apatite, zircon, and brown mica. In sections of about the same thickness, however, the depth of the colour in the Rámdongri blanfordite is not so deep as in the Kácharwáhi mineral. In some sections the c axis colour is greenish blue instead of pure blue.

The Kájlidongri occurrence.

Monoclinic pyroxenes having exactly the same type of pleochroism, only in much paler tints, also occur at Kájlidongri, Jhábua State, and Jothvád, in Nárukot State. It is not known at present whether these minerals are the same as the Kácharwáhi pyroxene, but as they exhibit the same type of pleochroism, which can for convenience be called the *blanfordite type of pleochroism*, they can be provisionally included under the term blanfordite. The blanfordite of Kájlidongri occurs at the northern end of the deposit associated with the winchite-bearing schists mentioned later on page 150. These schists are to be regarded as the product of the metamorphism of manganiferous sediments, the typical rock thus produced being composed of winchite, calcite, braunite, and quartz.

[1] *Amer. Jour. Sci.*, XXXVI, page 293, (1893).

Sometimes this rock contains pyroxene in addition; but the latter mineral occurs much more frequently in those varieties of the schists that are free, or nearly so, from calcite. Its commonest mode of occurrence is in the form of greenish patches in a white fine-grained quartz-rock usually containing winchite in addition. Sometimes these patches are more of the nature of cloudings and sometimes they take the form of rosettes, in which case the periphery of the rossette is composed of lilac winchite. Neither rosettes or cloudings are usually more than $\frac{1}{4}$ inch in diameter. Under the microscope the cloudings are seen to be indefinite aggregates; whilst the rosettes show radiating prismatic pyroxene individuals in the interior of the rosettes, with winchite prisms in parallel growth with them at the periphery. It is interesting to note that the orientation of the two minerals is nearly the same as regards their pleochroism, what differences there are being due to the different extinction angles of the two minerals. Thus the axes corresponding to blue in the two minerals are nearly parallel, whilst the pyroxene shows lilac with a tinge of brown at the same time that the amphibole shows lilac. The extinction angle of the pyroxene seems to be small in value. It will be seen that the colour of the Kájlidongri blanfordite as viewed macroscopically is slightly different to that of the Kácharwáhi mineral and that therefore one cannot be certain that it is the same mineral. It may, however, be that the difference is due simply to a slight difference in the amount of manganese present in the mineral.

The Nárukot occurrence.

It will be gathered from the above that the blanfordite of Kácharwáhi and Rámdongri occur in rocks that are probably of igneous origin, whilst the pyroxene from Kájlidongri, exhibiting the blanfordite type of pleochroism, occurs in a rock that is in all probability a metamorphosed sediment. At Jothvád in the Nárukot State, Bombay, pyroxenes exhibiting this type of pleochroism occur in both an igneous and a metamorphic rock; the latter is probably a metamorphosed sediment belonging to the gondite series as represented at this locality; whilst the igneous rock is intrusive in the rocks of this series, being an apophysis from the granite surrounding the hill in which these rocks occur. The granitic vein doubtless obtained the small proportion of manganese it contains, by absorption from the manganiferous rocks at the time of its intrusion into them. The granitic vein consists of microcline, with a smaller proportion of oligoclase, orthoclase and quartz, with a slightly manganiferous garnet and a pyroxene. The latter occurs in small stumpy prisms of octa.

gonal and hexagonal cross-section with the angles of a pyroxene. These prisms vary in length from $\frac{1}{8}$ up to nearly $\frac{1}{4}$ inch, and are dark brown with a reddish tinge. Under the microscope they exhibit the following pleochroism scheme :—

a = rose,
b = pale violet-brown to lilac.
c = greenish blue to pale blue.

In one case the a axis colour seemed to be green without any tinge of blue, so that, the other axis colour visible being pink, the mineral might be mistaken at first sight for hypersthene. That it cannot be this, however, is shown by the fact that the extinction is not straight, being 32° in the section that shows the green colour best. Moreover, the c axis colour in hypersthene corresponds with the vertical crystallographic axis $\dot{c}$, whilst in this mineral vertical sections often show the axis approximating to parallelism with the vertical crystallographic axis The angle $a \wedge \dot{c}$ varies from 0° to 53° and the angle $c \wedge \dot{c}$ from 37° to 68°. The index of refraction is high and the birefringence considerable, the polarization colours being sometimes as high as green of the second order, in sections in which the felspars polarize in greys. The specific gravity of the mineral is somewhat higher than that of the typical blanfordite of Kácharwáhi, being determined as 3·264 and 3·268 on two separate specimens by means of Klein's heavy liquid. The value of this constant can, therefore, be taken as 3·26 to 3·27 for the pyroxene from this rock. The mineral gives a distinct, but not very strong, reaction for manganese.

The metamorphic rock in which pyroxene exhibiting the blanfordite type of pleochroism occurs is a banded one, of which some layers have the outward aspect of a biotitic sandstone of rather fine grain, whilst others suggest a very fine-grained quartzite. Under the microscope the 'biotitic sandstone' is seen to be composed of quartz, microcline, apatite, black manganese-ore, an orange-coloured mica, and a pyroxene. The last occurs in ragged plates often intergrown with mica, whilst some plates form a sort of network enclosing in its meshes rounded prisms of apatite with some quartz. The pleochroism shows that a is pink and c blue, whilst the one extinction angle measured was $c \wedge \dot{c} = 19°$ A section of the bands resembling quartzite consisted essentially of a mosaic of quartz with a fair abundance of pyroxene.

The latter was pleochroic in very pale pink and green, corresponding to a and c respectively. The extinction angle $a \wedge c$ varies from 14° to 47°. In places the green tint looks distinctly bluish, and, in fact, when the tints are so pale, it is often very difficult to determine whether the c axis colour is blue or green. With the quartz polarizing in grey and white of the first order, the pyroxene polarizes in orange and red of the first order and purple of the second.

Comparing the properties of the various varieties of pyroxene noticed in the preceding paragraphs it seems that the type of pleochroism is approximately the same in all, namely :—

a = pink,
b = lilac,
c = blue,

the depth of these various tints varying very much in the pyroxenes of different localities. The above scheme, which is that of the typical mineral of Kácharwáhi, is subject to slight variations in the pyroxenes of other localities. Thus the lilac colour corresponding to the b axis may have a tinge of brown in it, causing this colour to approximate to the characteristic colour of titaniferous augite, whilst the blue colour of the c axis may have a greenish tinge in it, or may even be quite green, the latter phenomenon being noticed both in the igneous variety of Jothvád and in the variety, also igneous in origin, found at Rámdongri. The cause of the differences in the depths of the colours of the varieties from different localities may be due to differences in the amounts of manganese present, as also may be the differences in the values of the angle $a \wedge c$. But these points can only be settled by the isolation and chemical analysis of the different varieties ; until this is done it is not possible to say if we are dealing with only one variety of pyroxene of slightly varying composition, or whether more than one mineral has been included under the name blanfordite. If the latter be the case and later it be found necessary to give a separate name to some of the varieties, then the name blanfordite will be reserved for the variety for which it was first proposed, namely that of Kácharwáhi.

Manganhedenbergite.

Hedenbergite is a calcium-iron pyroxene of the formula $CaFe(SiO_3)_2$. When a certain proportion of the iron is replaced by manganese

the mineral is called manganhedenbergite and the formula can then be written as $Ca(Fe,Mn)(SiO_3)_2$.

Occurrence and characters.

I found a specimen of this mineral loose in a pit that had been excavated in the crystalline limestone at Junawáni in the Nágpur district. It had evidently been derived from the limestone, from which it had become separated, apparently through the decomposition of the enclosing rock. The specimen is a piece of one crystal about $2\frac{1}{2}$ inches long at right angles to the basal parting, and $2\frac{3}{4}$ inches by $1\frac{1}{2}$ inches across the longest and shortest measurements of this parting. The parting is well-marked and shows a vitreous to pearly lustre. Under the microscope it is seen to be the result of the formation of very thin twinning lamellæ. The lustre on rough cleavage fractures parallel to the vertical axis is resinous-vitreous and the colour greenish brown. In one place where the pyroxene is transparent the true colour is seen to be sherry-brown There are often a large number of small copper-coloured mica scales, intercalated along the well-marked prismatic cleavages so that their basal cleavage planes are parallel to the vertical crystallographic axis of the pyroxene. At one end the specimen passes into crystalline limestone in which there is a little spessartite. The hardness of the pyroxene is between 5 and 6.

Under the microscope the mineral shows well-marked basal partings and much less well-marked prismatic cleavages in sections parallel to the vertical axis of the mineral. But in the basal sections the characteristic prismatic cross-cleavages of a pyroxene are well seen. Extinction angles ($c \wedge \dot{c}$) on the sections prepared measured up to $33\frac{1}{2}°$, but it is not certain that any of these sections were truly parallel to the clino-pinacoid. In thin sections the mineral is colourless, but when the sections are thicker the colour is pale brownish. The mineral often shows various inclusions, particularly of mica, but sometimes of spessartite. Consequently, it was very difficult to prepare a pure sample for analysis, and it is probable that the sample analysed was not quite free from these inclusions ; but their amount cannot have been sufficient to account for nearly the whole of the manganese present. Hence there can be little doubt that the mineral really is manganhedenbergite and not hedenbergite containing inclusions of manganiferous minerals. The specimen analysed was found to have a specific gravity of 3·31. The analysis was carried out by

Composition.

Sub-Assistant S. Sethu Rama Rau in the Geological Survey laboratory, with the following result :—

Specimen No. 1061.

CaO	24·88
FeO	13·03
MnO	5·84
MgO	2·62
BaO	0·17
Al_2O_3	0·48
SiO_2	50·96
Combined water	1·09
Moisture at 100° C.	0·85
	99·92

In this the iron and manganese have been assumed to be in the protoxide condition ; for the state of oxidation was not determined, owing to the difficulty of obtaining a sufficient quantity of the pure mineral. The theoretical composition of hedenbergite is as follows :—

CaO	22·2
FeO	29·4
SiO_2	48·4

From this it will be seen that the Indian specimen corresponds to hedenbergite with a considerable proportion of the iron protoxide replaced by other protoxides ; these latter are the MnO, MgO, BaO, and a small proportion of the CaO, there being an excess of this last constituent over that required for the CaO group of the mineral.

Although only one large specimen of this mineral was found, it is not improbable that the small granules of pyroxene occurring in the crystalline limestone at this locality are also hedenbergite, though perhaps not always manganiferous.

Brown and Yellow Pyroxenes (Schefferite and Urbanite).

Occurrence.

In the Indian manganese-bearing crystalline rocks of Archæan age there are several occurrences of pyroxenes showing some tint of brown in the hand-specimen and shades of yellow and pale brown under the microscope. Pyroxenes of these tints have been found in the igneous rocks of the kodurite series in the Vizagapatam district, Madras, where they especially affect the manganese-pyroxenites ; whilst in the areas where the gondite series occurs such pyroxenes occur both in igneous rocks intrusive in the gondite series (in the Bhandára and Chhindwára districts, Central Provinces), and in the metamorphic rocks of the gondite

series (in Jhábua and Nárukot, in Central India and Bombay, respectively). As the rocks in which they occur show considerable variety as regards composition, it seems probable that the brown pyroxenes contained therein will also be found to vary considerably in composition and consequently in physical properties. In no case have I yet been able to carefully examine these pyroxenes either chemically or physically. In the case of the Vizagapatam examples, however, this would not be a matter of great difficulty, as the granules of the minerals are often of sufficiently large size for their extraction to be a matter of comparative ease. In the case of the igneous rocks containing these pyroxenes in the Central Provinces their separation for examination would also be fairly easy: but in the metamorphic rocks it would be quite another matter; for the pyroxenes usually occur in small granules very intimately associated with the other constituents of the rocks in which they occur, so that they are not as a rule conspicuous in hand-specimens.

Composition.

As far as I can tell from the published literature available, these minerals will probably be found, at least in some cases, to correspond more or less closely with already-described varieties of pyroxene. In most cases I have not proved that these minerals contain manganese; but considering the fact that they occur in manganiferous rocks and that those examples I have tested have given reactions for this element, sometimes weak and sometimes marked, it seems probable that they are all more or less manganiferous. There are two known varieties of pyroxene that are both manganiferous and of brown and yellow tints. These are *schefferite* and *urbanite*. The composition of these two minerals is shown below:—

Schefferite . . .	$(Ca,Mg)(Fe,Mn)(SiO_3)_2$
Urbanite . . .	$(Ca,Mg)SiO_3 + 2NaFe'(SiO_3)_2$
	(diopside) (acmite)

Schefferite and urbanite.

In two analyses of the latter mineral [1], 1·73 and 6·71 per cent. of MnO are returned, the MnO presumably replacing some of the protoxides in the above formula. Analyses of schefferite quoted by Dana show 6·20 to 8·32 per cent. of MnO. The essential difference in composition between the two minerals seems to be that urbanite, in addition to containing the ordinary molecule in which the oxides are all protoxides, as in diopside and schefferite, also contains the acmite molecule, in which a considerable proportion of soda is accompanied by ferric iron. Hence, as

[1] R. Mauselieus, quoted by Sjögren. *Bull. G. Inst. Upsala*, II, p. 77. 106, (1894), [Dana].

the percentage of manganese is roughly the same in the two minerals, the best way of distinguishing between them would seem to be to test them for sodium. A marked reaction for this element might then be taken to show that the mineral was urbanite, whilst failure to obtain this reaction to any but small extent might be taken to indicate the mineral to be schefferite. The above distinction would, however, only hold on the assumption that all the Indian yellow or brown manganese-pyroxenes must be either one or the other of the two minerals named above. This, of course, by no means follows; so that although the Indian brown and yellow manganese-pyroxenes can be provisionally divided into these two species by means of the sodium test, it will need the complete chemical analysis of various picked specimens to definitely settle this question. The characters of these two minerals that are of importance in addition to the chemical composition are given below, and were extracted from Dana's System of Mineralogy.

Schefferite:—Cleavage distinct, prismatic. Colour yellowish brown to reddish brown. Optically +. $Bx_a \wedge \dot{c} = c \vee \dot{c}$ 44° 25½[1]. Schefferite is found at the Långban manganese mine, Sweden. The variety known as iron-schefferite, on account of the large amount of FeO present replacing MgO and CaO, is black in colour when from Pajsberg, and then has $c \wedge \dot{c} = 49°$ to 59° for different zones in the same crystal. The variety from Långban is brown and has $c \wedge \dot{c} = 69°$.

Urbanite:—Cleavage, prismatic (*m*) distinct; (*c*) less so. H.=5 to 6. G.=3·52 to 3·53, colour brownish black to chestnut-brown. Strongly pleochroic, the following being the scheme of pleochroism:—

a=brown; b=yellow-brown; c=yellow.

$a \wedge \dot{c} = 16°$ to 22°. It is found at the manganese mines of Långban and Glakärn in Sweden.

In the following table I give those characters that have been ascertained for the yellow and brown pyroxenes of the rocks associated with or forming part of the gondite series. Since I have inserted in this list all the occurrences I have noticed of such pyroxenes in these rocks, it will be understood that they are of comparative rarity, considering the large number of occurrences of rocks of this series that are known. Of these occurrences, 1, 2, and 4 are in rocks that are in all probability of igneous origin, whilst 5, 6, and 8 are probably of metamorphic origin. No. 3 can be doubtfully regarded as of metamorphic origin, as it

[1] R. Mauzelius, quoted by Sjögren. *Bull. G. Inst. Upsala*, II. p. 77, 106. (1894), [Dana.]

seems to form part of the gondite series. In No. 7, Jothvád, the yellow pyroxene occurs in a portion of the rocks of the gondite series that has been included in the granite surrounding the hill in which these rocks occur; this rock is best considered as a contact rock formed by the interaction between the granite and the metamorphic rock it has picked up. As regards the pleochroism it must be noticed that the axis colours have been determined on sections in thin slices of the containing rocks. These sections necessarily cut the pyroxene in various directions and it is not usually possible to determine exactly what this is. Consequently in testing with a quartz wedge I have simply recorded the colour corresponding to the direction of greatest and least elasticity as *a* and *c* respectively, choosing for this test only those sections that seemed to be cut fairly close to planes parallel to the vertical crystallographic axis. When this section happened to be clino-pinacoidal then the colours recorded would be those really corresponding to the *a* and *c* axes. When however the section happened to be parallel to the ortho-pinacoid, then of course one of the axis colours recorded would be *b*, whilst the other would be compounded of both the *a* and *c* axis colours. In such a case, however, the extinction would be straight; to avoid this confusion I have chosen in all cases those sections giving the largest extinction angles and therefore those approximating most closely to the clino-pinacoid. The *b* axis colour must in all these cases be very similar to the colours recorded for the other axes, as it would otherwise be noticeable. From the figures given above for schefferite and urbanite it will be seen that the values of the extinction angles for these two minerals are as follows:—

Schefferite . . . . $a \wedge \dot{c} = 21°$ to $45\frac{1}{2}°$,
Urbanite . . . . $a \wedge \dot{c} = 16°$ to $22°$;

whilst in the examples in the table the value of this angle varies from 0° to 60°. Probably in most cases these Indian pyroxenes are monoclinic, but in the case of the Kájlidongri mineral it seems possible that it is orthorhombic.

It is difficult on such insufficient data to specify any particular examples of the above as either schefferite or urbanite, but perhaps the Sítapathúr specimen may be regarded as urbanite on account of its reaction for sodium.

TABLE 16.

Properties of the yellow and brown pyroxenes associated with the gondite series.

Locality.	Rock in which found.	Composition.	Colour in hand-specimen.	Pleochroism.	Extinction angle.	Cleavage and parting.	Birefringence.	
1. Kosumba, Bhandára district, C. P.	Pegmatite . .	...	Rich brown	a=Orange c=Yellow	$a \wedge \dot{c} = 12°$	...	...	...
2. Sítapathúr, Bhandára district, C. P.	Pegmatite . .	Reacts for Mn, Na, and Fe.	Brown	a=Yellow brown c=Brown	$a \wedge \dot{c} = 35°$ c=Bx_a	Cleavage ‖ m Parting ‖ c	...	G=3·33 *
3. Sukli, Bhandára district, C. P.	Pyroxene-spessartite-quartz-microcline-rock	...	Dark brown	Pale brown	...	...	...	...
4. Kachi Dhána, Chhindwára district, C. P.	Pyroxene-felspar-rock [microcline, orthoclase, albite, apatite, sphene].	Slight Mn reaction.	Brownish orange.	Pinkish brown to pale greenish brown	Up to 22°	...	2nd to 3rd order.	Probably +
5. Kájlidongri, Jhábua State, C. I.	Banded rock of Mn-ore, pyroxene, amphibole, and quartz.	...	...	a=Brown with tinge of pink. c=Yellow with sometimes tinge of green.	$a \wedge \dot{c}$ = usually 0°, but in one case 6°.	...	2nd to 3rd order.	...
6. Kájlidongri, Jhábua State, C. I.	Banded rock of quartz, rhodonite, yellow pyroxene, apatite, and spessartite.	...	Light resinous yellow.	...	...	...	...	...
7. Jothvád, Nárukot State, Bombay.	Rock composed of felspar, Mn-ore, mica, apatite, pyroxene, spessartite, quartz. An inclusion in granite.	...	Orange patches.	a=Light brown c=Paler brown to greenish and yellowish brown.	$a \wedge \dot{c}$=up to 36° or 40°, but in one case 60°.	...	...	...
8. Jothvád Nárukot State, Bombay.	Banded rocks composed of quartz, apatite, spessartite, rhodonite (?), yellowish pyroxene.	...	...	Very pale yellowish to brownish tints.	In one case $a \wedge \dot{c}$=39°, in another ext. ∠=43°.	...	In one case 1st order.	...

* Determined by G. G. Narke of Nágpur.

The Pyroxenes of the Vizagapatam District.

Brown pyroxene.

In the foregoing table I have not included the brown pyroxenes of the Vizagapatam district, where they are of much more common occurrence than in any of the other manganese areas, no doubt on account of the occurrence of the rocks I have designated manganese-pyroxenites. But with most of these I have done little more than determine the fact that they are pyroxenes. Amongst the pyroxenes of this district there at least three varieties or species, and perhaps four, that are probably manganiferous; for each of them may be found in every stage of blackening and alteration to manganese-ore. One of these is rhodonite and will not be considered here, but under the heading of that mineral. Of the others the best marked is a rich brown to orange-red variety forming by far the larger proportion of the manganese-pyroxenites of Táduru. This mineral occurs in rounded grains up to $\frac{1}{4}$ inch across, and under the microscope is brown in thick sections and pale yellowish in thin, the pleochroism being very weak. Measurements of the angle $c \wedge \dot{c}$ vary from 8° to 45°. Prismatic cleavage is often marked. The mineral gives a strong manganese reaction. What is probably the same pyroxene occurs at Sandapuram and Perapi.

Green pyroxene.

The second pyroxene is one that is a deep green as seen with the unaided eye, sometimes being even greenish black. It is found at Táduru in association with the pyroxene mentioned above, and also at Kodur, Chintelavalsa, and Perapi. Under the microscope the mineral usually exhibits some shade of brownish green when in thick sections, whilst in thin sections it is pale greenish to colourless. In one of the Kodur specimens the extinction angle $c \wedge \dot{c}$ ranges up to 35°, referred to the often very well marked prismatic cleavage traces. Sometimes the colour in thin slices is pale yellowish rather than greenish. In one such case the mineral was faintly pleochroic, a being colourless, and c pale yellowish.

Brownish green pyroxene.

Besides these two pyroxenes there seems to be a third, which is not green or brown as seen microscopically, but an intermediate colour, namely dark brownish green. This variety is also found at Táduru, in prismatic crystals up to 1 inch long. In very thick sections the colour is seen to be a pale brownish, but in thinner sections the colour seems to be a pale greenish. This variety is faintly pleochroic, and exhibits very oblique extinction. It is also found at Kantikapilli.

It is uncertain whether these are three distinct varieties of pyroxene as detailed above, or only three stages in a series of pyroxenes gradating one into the other. When the rock-slices are ground very thin, then they all become very pale in colour so as to look colourless at first sight. When so thin it is often very difficult, in fact almost impossible, to distinguish them from rhodonite, which is also colourless in thin sections and often occurs in the same rocks. When the rocks are fresh this is a matter of little consequence, because the pink colour of the rhodonite in hand-specimens at once distinguishes it from all the others.

Colourless pyroxenes.

In some of the rocks of Jothvád in Nárukot there are pyroxenes that under the microscope are seen to be colourless, but which do not indicate in the hand-specimen that they are rhodonite, the pink triclinic pyroxene, which is also colourless under the microscope. The rocks in which these occur are very fine-grained, one of them being composed of quartz, rhodonite (?), spessartite, sphene, and a rhombohedral carbonate, probably calcite. The pyroxene is practically colourless, shows marked cleavage and extinction angles up to 38°. It may be only one variety of the yellow pyroxene of this locality. The other rock in which such a pyroxene occurs is composed largely of piedmontite, with a good quantity of spessartite and apatite. The pyroxene is colourless to pale pinkish and in one case gave an extinction angle of $a \wedge \dot{c} = 42°$. This might be a variety of the blanfordite type of pyroxene, practically free from manganese. It is not known if these colourless pyroxenes are manganiferous or not. It does not perhaps necessarily follow that, because they occur in rocks that are themselves strongly manganiferous, therefore they contain more than a trace of manganese.

Jeffersonite.

This is a manganese-zinc pyroxene found at Franklin Furnace in New Jersey, U. S. A. It is practically a zinc variety of schefferite. The only record of this mineral in India is to be regarded as very doubtful, especially as there is, as far as is known, no specimen extant of what was originally determined as jeffersonite. This record is contained in the catalogue of the Reverend Mr. Muzzy's collection of Madura rocks and minerals[1]; the locality is given in J. H. Nelson's 'The Madura Country'

[1] E. Balfour, Catal. Govt. Cent. Museum, Madras; 'Madura, its rocks and Minerals'. p. 4, (1855).

p. 166, (1868), as near Mánkulam, about 11 miles N.-E. of Madura. Balfour's list also gives a second locality, namely Manapara.

Rhodonite.

This mineral is a pyroxene belonging to the triclinic system. It is a metasilicate of the composition represented by the formula $MnSiO_3$, which corresponds to a theoretical maximum % of manganese of 41·86. Frequently a small portion of the manganese is replaced by iron, calcium, or magnesium, and in rare cases by zinc. When these replacing constituents reach considerable proportions then a different name is sometimes given to the mineral. Thus when high in lime the mineral is called bustamite, and when high in zinc it is known as fowlerite. A separate name has not been given to the variety high in iron, whilst rhodonite containing large quantities of magnesia has not yet been recorded. The characters as given by Dana in his 'System of Mineralogy', page 379, are as follows :—

Characters.

Found either in crystals or massive, or as embedded grains. Cleavage perfect, prismatic (*m* and *M*); *c* less perfect. Fracture conchoidal to uneven; very tough when compact. H.=5·5 to 6·5. G.=3·4 to 3·68. Lustre vitreous; on cleavage surfaces somewhat pearly. Colour light brownish red, flesh-red, rose-pink; sometimes greenish or yellowish, when impure; often black outside from exposure. Streak white. Transparent to translucent.

Microscopic aspect.

Under the microscope the mineral is colourless and shows well-marked prismatic cleavages appearing as two series crossing at angles approaching a right angle ($mM=92^\circ\ 28\frac{1}{2}'$) in sections at right angles to the vertical crystallographic axis (see fig. 3, Plate 12), and as a series of parallel traces in sections parallel to the vertical axis. With regard to these parallel cleavage traces the extinction is very variable and usually very oblique. Dana does not mention any cases of twinned crystals of rhodonite. I have not yet seen any Indian specimens of rhodonite exhibiting definite crystal faces and consequently have not in this way recognised any cases of twinning. Under the microscope, however, I have not infrequently found examples of this mineral showing well-marked twinning, this being sometimes polysynthetic. Rock sections from Asalpáni (Bhandára district), Devi (Chhindwára district), Jothvád (Nárukot), and Mánegáon (Nágpur), exhibit this phenomenon. In the

Mánegáon example there is one section at right angles to the prism zone, showing two thin twinned lamellæ bisecting the angles of the crossed cleavages. They indicate that the direction of twinning is parallel to *b*. Other microscopic characters worth noticing are the low birefringence, so that the colours are of the first order in thin sections; and the absorption to be seen on relating the polarizer.

Identification.

Of the microscopic characters given above for this mineral the most serviceable in identifying it are its rose-pink colour; its granular crystalline character, often causing it to resemble in appearance a crystalline limestone, except for its colour; its hardness, so that it is scratched by a knife with difficulty or not at all; its extraordinary toughness when massive, as nearly all the Indian specimens are, so that it is very difficult to prepare good hand-specimens of the rhodonite-rock; and lastly its high specific gravity. As chemical tests, reactions for manganese and silica must be relied on. At first sight it might be confounded with rhodochrosite on account of its crystalline character and pink colour. The distinction between these two minerals is, however, easy to make, because rhodochrosite, being a carbonate, effervesces when heated with dilute hydrochloric acid, and is also much softer than rhodonite, being easily scratched with a knife.

The Indian rhodonites are not, however, always rose-pink in colour. At Guguldoho and Sitagondi, both in the Nágpur district, greenish grey rhodonite is to be found in massive pieces, whilst at Jothvád I found brown rhodonite, both these varieties being apparently fresh. It must be admitted that these two varieties have not been chemically examined, so that the deduction based on their general aspect and appearance under the microscope may be incorrect. When altered, rhodonite may show every shade of chocolate and dark brown up to brownish black and black.

Occurrence of rhodonite.

When Mallet's book on the Mineralogy of India was published in 1887 as Volume 4 of the Manual of the Geology of India, only two occurrences of this mineral in India were known. One of these was a specimen obtained by Mallet from a *lohari*, who found a quantity of it a foot or two below the surface in the southern part of the Mirzapur district, United Provinces. The other was the occurrence of rhodonite in association with braunite at Mansar near Rámtek in the Nágpur district, described by Mallet in a paper in the *Rec. Geol. Sur. Ind.*, XII, page 73, (1879). An examination of the specimen in the Museum from

this locality, labelled as braunite with rhodonite, has shown that what Mallet took to be rhodonite is really orange spessartite, patches of which occur in the midst of the manganese-ore in the specimen exhibited. The description of the mineral in the paper itself also points to spessartite rather than to rhodonite. Consequently the Mirzapur occurrence must be taken as the only one known until Mr. C. S. Middlemiss discovered loose blocks of this mineral, blackened externally, scattered on the road from Burjavalsa to Chintelavalsa, near Táduru, and near Thonaum, all of them in the Vizagapatam district just on the outskirts of the Eastern Ghâts. This was in the field season of 1903-1904. In the same field season I found the same mineral first at Rámdongri and then at many other places in the Bálághát, Bhandára, Chhindwára and Nágpur districts in the Central Provinces. The next season I was able to visit the occurrences noticed by Middlemiss, with the exception of Thonaum, and find the mineral *in situ* : in the same season I also found the mineral in the Ganjám district, Madras ; in Jhábua State, Central India, and in Nárukot State, Bombay. The following is a list of all the known occurrences of this mineral in India :—

Bombay —
  Nárukot State :—Jothvád.
Central India—
  Jhábua :—Kájlidongri.
Central Provinces —
  Bálághát :—Chikmárá, Sonegáon, Thirori.
  Bhandára :—Kurmura, Asalpáni I, Asalpáni II.
  Chhindwára :—Alesur, Bichua, Devi, Gaimukh, Ghoti, Wagora.
  Nágpur :—Peldongri, Chárgáon, Guguldoho, Junawáni, Kándri, Khandála, Mándri, Mándvi Bir, Mánegáon, Mansar, Panchála, Párasioni, Rámdongri, Risára, Sátak II, Sitagondi, Waregáon.
Madras—
  Gánjám :—Nautan-Barampur.
  Vizagapatam :—Chintelavalsa, Kantikapilli, Táduru, Thonaum.

In Bombay, Central India, and the Central Provinces, the rhodonite occurs in rocks of the gondite series, and is hence in all probability the product of the metamorphism of manganiferous sediments in the way explained on page 290. In Ganjám and Vizagapatam the rhodonite occurs in rocks that may be the result of solidification from the molten condition. That the metamorphic mode of formation is the characteristic one is shown by the frequency with which this mineral occurs in the rocks of the gondite series ; on the other hand, I have never found it in the rocks intrusive into the gondite series, where one might expect to find it if the mineral were at all commonly formed by solidification from fusion. This same tendency is shown by the fact that rhodonite

is never found in the typical members of the kodurite series of Vizagapatam, but only in those varieties I have designated the manganese-pyroxenites (see page 249). These, however, are nearly always found apart from the typical kodurite rocks, so that at first sight it might be thought that the mere fact of their containing rhodonite, considering what has been written above, might be taken to indicate that these manganese-pyroxenites are also of metamorphic origin and form a distinct series from the igneous kodurite series. It seems more probable, however, that the manganese-pyroxenites are also of igneous origin, since they are sometimes found in association with the typical kodurite rocks, as at Perapi and Kodur, for instance; and that the absence of rhodonite in the typical kodurite rocks is due to the fact that rhodonite requires about 42 per cent. of manganese for the formation of pure $MnSiO_3$; and that when many other constituents are present in the rock, so that the percentage of manganese is relat vely low, the manganese naturally forms silicates that contain a smaller percentage of manganese, such as the other manganiferous pyroxenes or manganese-garnets. The abundance of rhodonite in the manganiferous rocks of metamorphic origin is then explained by the frequency with which the original sediments from which the rocks of the gondite series were formed contained a high percentage of manganese. The same reasoning as for Vizagapatam explains why rhodonite is not formed in the rocks intrusive into the gondite series.

As already mentioned, rhodonite exhibiting measurable crystal faces has never been found in the Indian deposits, although such crystals are sometimes found in other parts of the world. This is probably due to its usual metamorphic origin, the rocks in which it occurs having been subjected to great pressures at the time of formation, so that as a rule they contain no open spaces or cavities. Such spaces as there are, have been formed by the action of waters subsequent to the formation of the rhodonite, so that if any such empty spaces are lined with crystals, they are of subsequently formed minerals, such as the various oxide minerals, rather than of rhodonite. This cannot, however, be the whole of the explanation why rhodonite crystals are not found, because the manganese-garnet, spessartite, associated with the rhodonite and formed under the same circumstances, frequently occurs in well-formed crystals, usually in a matrix of quartz, but sometimes in a matrix of rhodonite. Hence it seems as if rhodonite has very little tendency to take on well-crystallized forms. In the rocks of the gondite series it sometimes occurs as rhodonite-rock, forming

practically the whole of the rock. Then there are varieties of rhodonite-rock containing small quantities of spessartite or quartz, or of both; and from these there is every gradation through rocks composed of roughly equal quantities of rhodonite and spessartite, or more rarely of rhodonite and quartz, up to rocks composed practically entirely of spessartite or quartz. Whenever the rhodonite occurs in rocks with spessartite it seems to give the garnet a good opportunity to assume a crystalline form. On rare occasions, however, I have seen under the microscope rounded idiomorphic crystals of rhodonite enclosed in spessartite, as for example in a rock from Jothvád. As will be seen from the list of rocks of the gondite series given on page 329, this mineral may also be associated with rhodochrosite, amphibole, orthoclase, magnetite, manganese-mica, and barytes. In the rocks of the gondite series the rhodonite individuals are sometimes as large as 1 or even 2 inches across, then exhibiting well their perfect cleavage, and often enclosing other minerals, especially spessartite, poikilitically.

In the manganese-pyroxenites of the Vizagapatam district the rhodonite usually occurs in prismatic individuals together with the other pyroxenes in the rock. Owing to the rather loose state of aggregation, in some cases, of the granules of these pyroxenites, these prismatic individuals are often easily detached and are sometimes as much as an inch in length.

Alteration.

The appearance of a piece of rhodonite-rock under the microscope is shown in figure 3 of Plate 12, which illustrates why the rock often resembles a crystalline limestone in structure as seen in the hand-specimen. For the rock to be so fresh as in this example is, however, not the rule; for this mineral is very prone to alteration. This alteration seems to start along the cleavage cracks of the mineral as shown in figure 4 of Plate 12, and then to spread in all directions so as to leave smaller and smaller clear areas between the altered portions, the final result being a blackened mass of manganese and iron oxides. When the alteration is taking place, the product seen along the cracks is not all black in colour, but areas and strings of a curious orange to yellow-brown substance, polarizing as an aggregate in the way serpentine sometimes does, are also formed. The nature of this substance is not known, but it may be an intermediate product between rhodonite and manganese oxide. In some cases, moreover, the alteration of the rhodonite does not seem to take place along the cleavages in particular, but to spread out irregularly over the mineral in moss-like or dendritic forms, and as irregular cloudings,

these all being dark brown in colour. The opaque portion, moreover, seems to be black and brown in patches, the brown perhaps indicating that the fresh rhodonite contains a considerable proportion of iron oxides. In some cases the final result seems to be psilomelane, in others braunite, the intermediate product being an indefinite dark brownish black ore that can be scratched with comparative ease. It seems probable that the latter variety would not pass into compact braunite without the introduction of manganese in solution from other portions of the mass of rock in which the altering mineral occurs. The consequence of the ease with which this mineral undergoes oxy-alteration is that all outcrops of rhodonite-bearing rocks are black (or dark brown) ; but when the rock is broken open it is frequently found that this blackening does not extend for more than 1 to 2 inches in depth, the bright pink mineral lying beneath. Nearly all the loose blocks first found by Mr. Middlemiss near Chintelavalsa and Táduru in the Vizagapatam district, are completely blackened outside and are quite fresh inside, the blackened coat being often as much as 2 inches thick. This proves that the blackening of the mineral is going on at the present day ; for these blocks must have been blackened, at least on most sides, since they were detached from their original position *in situ*, which lies on the hill-side above, and from which such blocks are presumably still being detached under the influence of the ordinary meteoric agencies.

Use as an ornamental stone.

In my paper 'Manganese in India' [1], I have already drawn attention to the fact that rhodonite-rock in other parts of the world is frequently turned to account as an ornamental stone on account of its great beauty when polished, the most famous locality for this industry being the Ural Mountains. In some of the deposits of the Central Provinces there are considerable amounts of beautiful examples of both rhodonite-rock, and of rose-pink rhodonite-rock studded with orange-coloured spessartite crystals. As localities for the former Mánegáon and Risára in the Nágpur district may be mentioned, whilst fine examples of the second variety are to be found at Chárgáon in the same district.

I have, since that paper was written, been able to re-visit and examine the Mánegáon deposit. It had been much more opened up than at the time of my first visit ; and I must confess my disappointment at the small quantity of good rhodonite-rock suitable for use as an ornamental stone that seems to be available, this being due, not to any deficit in the quan-

[1] *Trans. Min. Geol. Inst. Ind.*, I, p. 120, (1906).

tity of rhodonite, but to the large proportion of it that is too much blackened to be of use; for it must be mentioned that a small proportion of oxy-alteration, as long as it does not give rise to decayed spots, improves, if anything, the beauty of the rock, on account of the mottlings, spots, and moss-like markings it produces. A considerable proportion of small pieces of rock suitable for the manufacture of small ornaments could be obtained, but it would be very difficult to obtain larger pieces suitable for such purposes as the manufacture of table tops.

Manganese-amphiboles.

Although, in the Archæan manganese-silicate-rocks of India, the commonest of the dark silicates are garnets, with pyroxenes next, yet amphiboles have been found at several localities, in no case, however, except at Kájlidongri, in any but very small quantities, forming no appreciable proportion of the whole mass of rock in which they occur. These amphiboles can be divided into two main divisions according to their colour. One division is blue, lilac, or lavender, in colour and will be considered under the heading of *winchite*, a name given to the variety found at Kájlidongri. These have been definitely determined to be manganiferous. The amphiboles of the other group vary from yellow to greyish-green, greyish, and chocolate, although the latter colour is probably the result of alteration. These varieties have not yet been carefully investigated, but on account of their association are probably manganiferous and will be considered under the heading of *dannemorite*, the described amphibole to which they bear the closest resemblance. As regards occurrence, it is to be noticed that no amphiboles have yet been observed in the igneous manganiferous rocks of the kodurite series of the Vizagapatam and Ganjám districts, and that all the known occurrences of amphiboles in Indian manganiferous rocks are in the varieties that I look upon as metamorphic in origin, belonging always to the gondite series. They have been found in all of the three areas in which rocks of this series have been recognized, namely, Nárukot, Jhábua, and the Central Provinces.

Foreign manganiferous amphiboles.

Before considering the various occurrences of these amphiboles in India it will be well first to give a short account of what is known about the manganiferous amphiboles of other parts of the world. There are two main divisions of the manganiferous amphiboles, corresponding to the two following minerals:—

Dannemorite . . . $(Fe,Mn,Mg)\,SiO_3$,
Richterite . . . $[(K,Na)_2,Mg,Ca,Mn]\,SiO_3$.

which are to be regarded as two distinct varieties of the non-aluminous section of the amphiboles. There are also some amphiboles of more aluminous nature that contain small proportions of manganese, namely arfvedsonite, barkevikite, and philipstadite; but since, judging from the published accounts, none of the Indian specimens are likely to come under any of these species they will not be further considered here.

The data given below concerning these two minerals are taken from Dana's 'System of Mineralogy' and its appendix and the references to the original papers describing these minerals will be found in that work.

Dannemorite.—Under this name are included the minerals to which the names of asbeferrite, silfbergite, and hillängsite have been given. All the occurrences of this mineral are at Swedish localities. In colour the mineral varies from ash-grey through greyish white, greenish grey, and brownish grey, to yellowish brown and dark yellow, the different colours corresponding, no doubt, to the differences in composition of the different specimens analysed. The mineral is in one case described as being fibrous or columnar like asbestos. The variety silfbergite is distinctly pleochroic, and has an extinction angle on *b* of 13° 45′, and has G = 3·446 and H = 5·5.

The four analyses quoted by Dana show the following range in the amounts of the various constituents:—

SiO_2	46·25—48·89
Al_2O_3	0 — 1·46
FeO	28·17—40·40
MnO	8·34—12·08
MgO	2·92— 8·39
CaO	0·73— 3·22

from which it will be seen that the chief constituents are silica, and ferrous and manganous oxides, alkalies being absent.

Richterite.—Under this name are included the varieties known as marmairolite and astochite. The colour varies considerably in the different kinds, richterite being brown, yellow, or rose-red, marmairolite yellow, and astochite blue to greyish violet. The extinction angle $c \wedge \dot{c}$ is given as 17° to 20° for richterite, whilst the extinction angle of astochite is given as 15° 40′ for the blue crystals and 17° 15′ for the greyish-violet ones. The specific gravity of these minerals varies from 3·05 - 3·10. Six analyses quoted by Dana show the following limits of composition:—

SiO_2	52·23—56·27
Al_2O_3	0 —23·31
FeO	0·15— 2·80
Fe_2O_3	0 — 1·77
MnO	4·86—12·71
MgO	17·82—21·89
CaO	5·20— 8·43
K_2O	0·66— 6·37
Na_2O	2·77— 6·33

From this it will be seen that the chief constituents are silica, manganous oxide, magnesia, lime, and alkalies, the only constituents that are prominent in both dannemorite and richterite being the silica and manganous oxide. Richterite and its varieties all come from Långban and Pajsberg in Sweden.

We can now pass to the consideration of the Indian amphiboles found in the manganese-ore deposits and associated rocks, treating the yellow and greyish ones under the heading of dannemorite and the lilac and blue ones under the heading of winchite, which, as will be shown below, is allied to richterite.

Yellow and Greenish-grey Amphiboles (Dannemorite ?).

The amphiboles of this group can for convenience be divided into two sections, those from the Central Provinces, and those from Kájlidongri, Central India.

In the Central Provinces the following occurrences may be noted :—

Bálághát district :—	
1. Chikmára . . .	In gondite.
Bhandára district :—	
2. Hatora . . .	In gondite.
Chhindwára district :—	
3. Bichua . . .	In gondite.
4. Bichua . . .	In rhodonite-gondite.
5. Wagora . . .	In spessartite-rhodonite-rock.
Nágpur district :—	
6. Kándri . . .	In gondite.
7. Nandapuri . . .	In gondite.
8. Sátak I. . . .	In gondite.
9. Sitagondi . . .	In spessartite-rhodonite-rock.
10. Pársioni . . .	In orthoclase-rhodonite-gondite with rhodochrosite.
11. Páli . . .	In piedmontite-gneiss (granulite).

Central Provinces.

It will be seen from the above that the rock in which this amphibole usually occurs is gondite or spessartite-quartz-rock, but it also not unfrequently occurs in varieties containing rhodonite. The gondite may be either the fine or coarse-grained variety; but is more usually the coarse-grained type, perhaps because the amphibole is more conspicuous in the coarser varieties and so more likely to be noticed and collected. In the coarse varieties the spessartite

is often $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter. In one specimen from Hatora, however, the amphibole occurs as rather conspicuous radiate white asbestiform needles often altering to a greenish black colour, on the parting planes of a fine-grained variety of gondite. In the Kándri example the rock is also fine-grained, the amphibole, the determination of which is somewhat doubtful, being noticed only under the microscope. Usually the mineral is conspicuous in the hand-specimens, appearing as radiate or semi-radiate bundles or sheaths, usually with the fibres $\frac{1}{4}$ to $\frac{1}{2}$ or even 1 inch in length. When fresh the colour of these sheaths varies from greenish grey to brownish green and yellowish or buff. The fresh mineral is best seen in the specimens from Pársioni and Chikmára (collected by Mr. C. M. P. Wright). When in this fibrous condition the lustre of the mineral is silky. But sometimes the width of the individual fibres of the aggregate is greater and then the mineral tends to be bladed in appearance. Very frequently the mineral is partly altered, the colour then being usually some shade of chocolate, whilst the mineral is softer than when fresh. Under the microscope this alteration is seen to take the form of a brownish powder deposited along both the cleavages and cross cracks of the mineral. Owing to the fibrous or thinly prismatic nature of the mineral it is very difficult to obtain good sections for microscopic examination, the fibres separating out long before the section is sufficiently thin. Nevertheless, several prismatic sections have been obtained; but it is almost impossible to obtain a cross section showing the cleavages characteristic of amphibole. In one specimen from Bichua, however, such a section was obtained exhibiting the cross-cleavages of the amphibole group and thus confirming the deduction as to the nature of this mineral. The prismatic sections show extinctions ($\mathfrak{c} \wedge \dot{c}$) up to 22°, the highest value in several examples approximating to this figure. The birefringence is low, the polarization colours being of the first to second order. In some cases the mineral is practically colourless as seen under the microscope; but in others it shows pale colours, then being slightly pleochroic. Thus a slide of the Hatora occurrence shows:—

$\mathfrak{c}$ = very pale brownish yellow,
$\mathfrak{b}$ = slightly darker brownish yellow;

whilst one from Bichua shows a pleochroism of pale greenish brown to colourless.

From their mode of occurrence and general appearance it seems probable that all the above occurrences are of the same mineral, except that of Páli, which is in a piedmontite-gneiss. This amphibole is yellow-

ish white in hand-specimens and colourless under the microscope. Considering the fact that all the constituents of the rock in which it occurs are non-manganiferous except the piedmontite, it is not at all improbable that this amphibole is also non-manganiferous.

Kájlidongri.

At Kájlidongri I found two occurrences of amphiboles, leaving the winchite entirely out of consideration. One of these is in a banded rock composed of yellow pyroxene, yellow amphibole, and quartz, with a little felspar. The pyroxene is that noticed on page 136. The amphibole is in irregular prismatic individuals as seen in the microscope section, and shows the following pleochroism :—

a = yellow with a brownish or orange tinge,
b = pale straw, sometimes with a greenish tinge.

The crystals are of low birefringence, showing under polarized light a very patchy appearance. This is due to zoning, the outer portions of the crystals having a larger value for the angle $a : c$ than the inner, with a more or less gradual change from one to the other. One example showed patches with an extinction angle of $22\frac{1}{2}°$, in a main portion with extinction angles of 45° to 54° ; whilst another showed a change from 10° inside to 37° outside. In this character the mineral very closely simulates winchite. The other occurrence is in a rock composed of crimson mica, talc, apatite, and the amphibole. The latter was not evident in the hand-specimen, and under the microscope practically colourless, so that it might be either tremolite or a very pale variety of winchite.

From a consideration of the foregoing it seems that in general aspect the amphibole of the Central Provinces bears considerable resemblance to dannemorite.

Winchite.

Of this mineral, originally found by Mr. H. J. Winch of Meghnagar at the manganese mine, Kájlidongri, Jhábua State, Central India, I gave a preliminary description in the *Rec. Geo. Surv. Ind.*, XXXI, pp. 235, 236. (1904) ; and in the *Trans. Min. Geol. Inst. Ind.*, I, p. 79, (1906), announced the name of it as *winchite*, after the original discoverer. In February 1905 I was able to visit Kájlidongri and collect considerable quantities of the mineral, with the rocks in which it occurs. As the result of a study of a large number of thin sections under the microscope I am

able to add considerably to the original description, and propose to give here a general account of the mineral.

Occurrence.

As will be seen by consulting the sketch-plan of the Kájlidongri deposit given on Plate 19, the chief spot for this mineral is at the north end of the deposit, where the rocks containing it form a band about 4 feet thick, with a strike and dip conformable to that of the ore-deposit.[1] The associated rocks had not been clearly exposed at the time of my visit, but it looked as if the winchite-bearing rocks formed one wall of the deposit at this point; they were probably formed by the metamorphism of calcareous manganiferous sediments, accompanying the ordinary manganiferous sediments from which the ore-body proper was formed by metamorphism and subsequent chemical alteration. The band in which the winchite occurs is made up of layers, ranging up to 4 inches in thickness, of various composition, nearly all of them containing winchite. The most characteristic rock is one composed of winchite, calcite, quartz, and the magnesian variety of braunite of which an analysis is given on page 68. Another common occurrence is in a rock that may be described as a very fine-grained white or pale grey quartzite containing abundance of lavender-coloured winchite with greenish spots and crystals of blanfordite. This rock is usually banded and is often friable so as to simulate a sandstone. Besides these two varieties there are several others of less importance, which contain some or all of the foregoing minerals, with some or all of the following minerals in addition—plagioclase, apatite, crimson mica, and talc. In the rock first mentioned, which from its structure may be called a winchite-schist, the winchite is usually in more or less flattened crystals tending to be of a bladed shape. They are of a light blue colour, with perhaps a tinge of lavender. Owing to the predominance of this mineral the whole rock is of a striking light blue colour. In the quartzites mentioned above the mineral occurs either as radiate tufts of lavender colour on the parting planes of the rock, or as small isolated prisms, often beautifully formed, which may be either of a rich deep cobalt blue with a tinge of lavender, or, when smaller, of a rather dark lavender colour. Sometimes, as noticed on page 128, the radiate tufts have blanfordite of green colour in the centre with peripheral winchite. In the schist the winchite individuals usually range from 0·5 to 2·0 cm. in length. In the quartzite they range from 1 or 2 mm. up to perhaps as much as 1 cm. This mineral also occurs, though but sparingly, in the vitreous quartzites adjacent to

[1] An unimportant occurrence in another part of the deposit is noticed on page 686.

the main winchite-bearing band. In this rock the mineral is found in small tufts tending to be radiate in structure.

Crystallographic characters.

From the fine-grained quartzite mentioned above I have been able to obtain several small crystals sufficiently well formed to permit of the measurement of the angle mm'''. In general these crystals are simple prisms, showing no other faces, and with irregular terminations. But in one case an embedded crystal was found showing, in addition to the prism, the clino-pinacoid b, a small steep clino-dome, and the basal plane, c, sloping slightly forwards. The portion of the crystal visible is only 1·5 mm. long, and about 1 mm. from acute angle to acute angle of the prism.

For the determination of the angle mm''', I was able to separate three suitable crystals. These can be designated I. II. III.

I. This is 4 mm. long and 1·5 mm. wide and is dark blue in colour. It is a simple prism slightly tapering. All the faces are rather dull owing to the projection of included specks of braunite. One face is cracked at one end and another has a little white crust on a portion of it. Using only the acute-angled edges of the crystal several measurements made over each of these edges gave a mean value of 55° 17′ for the prism angle mm'''.

II. This is the best crystal and is an unusually transparent one of lavender-blue colour. It is 2·5 mm. long and 0·08 mm. broad. It is a simple prism, with the faces finely striated in a vertical direction, and with a few included specks of braunite. The reflections from all the faces except one were good. Measurements taken all the way round, using all the faces gave 55° 27½′ as the mean of several determinations. Lying on one of its faces on a glass slide on the stage of the microscope the mineral shows well the characteristic pleochroism of winchite, namely from rich lilac, or even violet, to sky-blue. The axis corresponding to the lilac colour is the one nearest to the vertical crystallographic axis, so that the crystal is one of what has been designated the basic variety. The crystal is irregularly terminated at both ends.

III. This is a portion of a large crystal, and is 0·6 cm. long and 4·5 mm. broad. It is opaque darkish cobalt-blue in colour

and has its surface lustre-mottled to a certain extent owing to numerous small inclusions of the usual manganese-ore (braunite). The reflections from three of them, however, are sufficiently good for measurement. The mean of the values obtained by making use of the two edges thus available was 55° 30′, and then 55° 28½′ for a re-determination, giving a mean of 55° 29¼′.

Thus we see that the mean value for crystal II is 55° 27¼′ and for III is 55° 29¼′. Hence 55° 28¼′, or for simplicity 55° 28′, can be taken as the value of the angle mm''' for winchite. Considering the fact to be noticed below, that there is a great variation in the extinction angles measured in different individuals and even in different parts of the same individual, and that this variation is probably an expression of the variable composition of the mineral, we should expect a certain variation in the interfacial angles of different specimens. Hence the value for the angle mm''' as measured on crystal I, 55° 17′, may be that corresponding to a specimen of slightly different composition.

Hence the value of the angle mm''' may be taken varying from 55° 17′ to 55° 28′. For the sake of comparison the values of this angle mm''' for the various amphiboles to which winchite may be related are given below. They are taken from Dana's Mineralogy :—

Amphibole . .	55° 49′
Richterite . .	56° 7′
Astochite . .	56° 27′ (cleavage angle).

Pleochroism. Under the microscope the mineral is found to exhibit the following pleochroism :—

a = pinkish lilac.
b = paler lilac.
c = blue.

In one case, in a thick slide, the following was the pleochroism observed :—

a = amethystine-rose,
b = pale,
c = bright sky-blue,

the b axis colour being the palest of the three.

Extinction angles.

With regard to the variable extinction angles and marked zoning exhibited by winchite I will quote what I have said in the original account[1] :—

'By polarized light it is seen that the mineral shows irregular zoning, due probably to varying composition. As the inner zone seems to have the presumed manganese-ore dust developed in it more readily than the outer shell, it seems probable that there is a gradual change from the most basic composition inside to the most acid outside. This change in composition is accompanied by a change in position of the elasticity axes. For the basic portions of the amphibole the a elasticity axis is the one nearest to the vertical crystallographic axis $\dot{c}$. The angle may be as low as 16°, but as one passes from the interior, most basic, portion to the outer, most acid, portion in a zoned individual, the axis a gradually swings away from the vertical crystallographic axis $\dot{c}$ till it makes an angle sometimes as large as 70° with $\dot{c}$. The elasticity axis c has of course now rotated into proximity with the crystallographic axis $\dot{c}$, making with it an angle of 20°, so that $c \wedge \dot{c} = 20°$.

'As will be seen from the pleochroism scheme, this rotation of the elasticity axes is accompanied by a change from lilac to blue, as the elasticity axis nearest the vertical crystallographic axis changes from a to c; consequently these compound crystals do not show even colouring, but are in irregular patches of blue and lilac. Though some of the crystals in the microscope slide are almost entirely of one composition, either basic or acid, it is easy to distinguish them at once by the colour corresponding to the elasticity axis nearest $\dot{c}$ thus' :—

Chemical character.	Axis nearest $\dot{c}$ is	Corresponding colour.
Basic	a	Pinkish lilac.
Acid	c	Blue.

The assumption made above as to the chemical character of the different zones is of course difficult to prove or disprove. I have not been able to separate for analysis portions of the acid and basic varieties, and I doubt if this is possible. As the analysis to be given below shows such a small proportion of manganese in the mineral, it seems difficult to believe that the small differences in the amounts of this element possible in the different zones of the mineral could produce such striking variations in the extinction angles; and that, even if this be so, the small proportion of manganese present could, by separating out in the oxide form, give rise to such considerable clouds as are referred to above. For convenience sake, however, I shall continue to refer to these two portions

[1] *Rec. Geol. Surv. Ind.*, XXXI, p. 235, (1904).

of the mineral as acid and basic. There is little to add to the above account of the extinction angles of this mineral. In those examples in which zoning is absent the whole mineral seems to be as a rule composed of the basic variety, and the most usual value of the angle $a \wedge c$ in these unzoned crystals is 20° to 26°, usually nearer the latter figure. In one case where I found an entirely acid example without zoning the extinction angle $a \wedge c$ was 38°.

Double refraction.

In the first account of this mineral I said that the polarization colours rarely rise above the first order. But now, after examining a large number of sections, I find that this is not exactly true. Sometimes the colours are as high as green and yellow of the second order. In the zoned crystals the interior more basic portion exhibits somewhat higher colours under polarized light than the outer more acid portions. It is possible that this difference is due to the section of a crystal being slightly thinner at the edges, so that a small thinness of the adjoining mineral passes under it at this point. From a careful examination of the sections, however, I do not think this is the case, but that the difference in birefringence is a true one. I have not been able to measure the birefringence, except in the chance sections one gets under the microscope. But from these, by comparing the colours exhibited with those of the quartz usually present in the same slide, I have deduced the values of the birefringence given below. In one section of a zoned individual, $\gamma - \alpha$ worked out as 0·030 for the most basic portion, and 0·024 for the most acid. In another slide, the value of $\gamma - \alpha$ worked out as 0·020 to 0·022, as deduced from several sections irrespective of their basicity. In one section giving straight extinction and showing the a and b axis colours, and consequently to be regarded as the basic variety, the polarization colour, being the same as that of quartz, indicated the value of 0·007 to 0·008 for $\beta - \alpha$. It must be noticed that sections of winchite often exhibit the polarization colour usually referred to as ultra blue, together with various other allied colours of curious tint not belonging to Newton's scale. These are particularly prominent in well-zoned individuals, so that it seems probable that it is due to the outer acid zone of a crystal compensating the double refraction of the inner basic zone. From the above it will be seen that the general values for the birefringence of this mineral may be given as follows:—

$$\gamma - \alpha = 0{\cdot}020 \text{ to } 0{\cdot}030,$$
$$\beta - \alpha = 0{\cdot}007 \text{ to } 0{\cdot}008.$$

Separation of the mineral.

To obtain material for the chemical examination of this mineral was a matter of considerable difficulty. The rock chosen for this purpose was the winchite-schist composed of winchite, calcite, quartz, and braunite. This was broken up to pass a 100-sieve and after removing the greater portion of the quartz and calcite by means of Sonstadt's solution, of such a strength that most of the amphibole and braunite sank and most of the quartz and calcite floated, the impure mixture of braunite and amphibole was treated with concentrated Sonstadt's solution ($G=3{\cdot}25$) and separated into two portions, one being chiefly amphibole and the other a mixture of amphibole and braunite. The amphibole in the latter fraction contained an abundance of included black granules tending to show square outlines and doubtless to a large extent braunite, though some of it may have been some indefinite oxide of manganese produced by alteration of the mineral. It was doubtless to these inclusions that this amphibole owed its higher specific gravity, rather than to an appreciably different composition: for although, as seen under the microscope, the majority of the crystals seemed to be of the type I have described as basic, yet there were also some of the acid ones and some of the composite zoned individuals. The amphibole that floated in Sonstadt's solution contained abundance of included and attached calcite and much less of the included manganese-ore. The amphibole itself seemed to consist of the basic and acid varieties, with some of the composite zoned individuals. This portion of the amphibole was then treated with Sonstadt's solution of specific gravity 2·959 in which it nearly all sank. The material that sank was then left overnight in hydrochloric acid diluted to over 1 in 50, to remove the adherent calcite. From an examination of the amphibole under the microscope I do not think that this acid attacked the amphibole to any appreciable extent. The amphibole was then treated with a solution of specific gravity 3·024, in which most of the mineral floated, whilst a portion remained suspended, and some sank. The portion that floated was examined under the microscope and found to be very nearly free from included manganese-ore. It was subjected to one or two more separating operations and then used for analysis, the amount so available being 0·383 grammes only. The separated material was carefully examined under the microscope and it was found that the majority of pieces, which were in the form of small prismatic chips, were transparent and quite free from inclusions. The few inclusions present were evidently braunite; but they were so small in comparison with the volume of the amphibole that I do not

think they can have, appreciably, affected the composition, not even to the extent of the small amount of manganese that the analysis shows to be present. From the above it will be seen that the specific gravity of the pure mineral analysed lies between 2·959 and 3·024; it can therefore be taken as 3·0. Doubtless there are some few grains that lie outside the above limits, but the majority of such owe their greater specific gravity to the inclusions of manganese-ore. Perhaps, allowing for variations in composition, we can give the specific gravity of the mineral when free from inclusions as ranging from 2·95 to 3·05. The colour of the pure specimen of the mineral thus obtained was a bright azure blue as viewed in bulk in a glass tube, whilst under the microscope each tiny prism showed its distinctive pleochroism.

Specific gravity.

The material thus obtained was analysed by Mr. T. R. Blyth, of the Geological Survey of India, with the following result:—

Chemical composition.

SiO_2	55·64
Al_2O_3	1·08
FeO	6·35
MnO	0·77
MgO	22·09
CaO	7·64
Na_2O	2·89
K_2O	0·98
Loss on ignition	2·95
Moisture at 100° C.	0·14
	100·53

He recorded the absence of titanium, chromium, zinc, barium, phosphorus, and flourine. The amount of material available was not sufficient for the determination of the state of oxidation of the iron and manganese. In the first place I assumed the above to be the correct state of oxidation and converted all the protoxides into metasilicates of the general formula $RSiO_3$, taking for the purpose the requisite amount of SiO_2. In the same way the Al_2O_3 was converted into a silicate of the formula $Al_2O_3.3SiO_2$. After doing this 2·65 per cent. of silica was left over. If the loss on ignition be assumed to be due to combined water, 9·89 per cent. SiO_2 would be required for the formation of H_2SiO_3. I then supposed the iron to be present as Fe_2O_3 and converted this into

$Fe_2O_3.3SiO_2$, as before leaving the loss on ignition out of account. There was then found to be an excess of only 0·03 per cent. of SiO_2. On this interpretation an allowance has to be made in the analyses for a conversion of the Fe_2O_3 into Fe_3O_4 on ignition. The analysis can then be restated as follows, on the assumption that the iron is in the form of Fe_2O_3 :—

SiO_2	55·64
Al_2O_3	1·08
Fe_2O_3	7·06
MnO	0·77
MgO	22·09
CaO	7·64
Na_2O	2·89
K_2O	0·98
Loss on ignition	2·71
Moisture at 100°C.	0·14
	101·00

This can be arranged as follows :—

$MgSiO_3$	55·43
$CaSiO_3$	15·87
Na_2SiO_3	5·70
K_2SiO_3	1·61
$MnSiO_3$	1·42
$Fe_2O_3{\cdot}3SiO_2$	15·03
$Al_2O_3{\cdot}3SiO_2$	3·06
Loss on ignition	2·71
Moisture	0·14
	100·97
Excess SiO_2	0·03
	101·00

The formula corresponding to this is :—

$$14\,[(Mg,Ca,Na_2,K_2,Mn,)SiO_2] + [(Fe,Al)_2O_3.3SiO_2];$$

or, with all the oxides shown separately, it is :—

$$(MgO)_{53}\,(CaO)_{13}\,(Na_2O)_4\,(K_2O)_1\,(MnO)_1\,(Al_2O_3)_1\,(Fe_2O_3)_4\,(SiO_2)_{89}.$$

If the analysis of this mineral be compared with those given for richterite and its relatives on page 146, and with that of the theoretically pure tremolite, which is as follows :—

SiO_2	57·7
MgO	28·9
CaO	13·4
	100·0

it will be seen that winchite has affinities with both tremolite and richterite. Neglecting the state of oxidation of the iron, winchite is to be regarded as a tremolite containing, in addition to magnesia and lime, as its base constituents, oxide of iron in considerable quantity with a small amount of alkalies and manganese oxide. Or it may be regarded as a variety of richterite with the manganese to a large extent replaced by iron, and with a smaller amount of alkalies than richterite usually contains. The latter is the closer relationship and consequently this amphibole is to be regarded as a variety of richterite. The variety of richterite to which it shows the closest relationship is astochite, the similarity of these two minerals as regards their colours being very close. The reason for giving the Indian mineral a distinct name is found in its interesting optical behaviour, which is no doubt due to its somewhat different composition. As both astochite and winchite show blue and violet or lavender colours, it is interesting to note that in astochite the MnO ranges from 6·49 to 12·71%, and the FeO is only 0·15 to 0·21%; whilst in winchite the relative abundance of these two constituents is just the reverse, the FeO being 7·06 per cent. and the MnO only 0·77%. From this it is not evident which element is the cause of the colouration of the mineral, if it be either of them and not the alkalies.[1] As regards the angle mm'', however, winchite is more closely related to tremolite than to a tochite (see page 152). Sometimes varieties of winchite are found at Kájlidongri that are white in colour and are then indistinguishable in appearance from tremolite.

[1] It is interesting to note, however, that an azure-blue pyroxene from Middle Gila, New Mexico, noted by G. P. Merrill and R. L. Packard in the *Amer. Jour. Sci.*, XLIII, pp. 279, 280, (1892), was found to be a variety of diopside containing 1·11 per cent. of FeO, and no other constituents except SiO_2, MgO, and CaO. The authors ascribe the colouration of the mineral to this FeO. Under the microscope, however, the mineral is colourless.

Juddite.

Associated with the blanfordite of Kácharwáhi in the Nágpur district there is a manganiferous amphibole with a pleochroism analogous to that of the blanfordite with which it is associated; but it is, if possible, still more beautiful. The tints seen in a microscope slide showing a considerable number of sections of this mineral consist of various shades of rose, carmine, lilac, purple, blue, green, orange, and orange-pink. These tints are often very delicate, and their great variety is doubtless due to the combination of the colours corresponding to the different axes in varying proportions in various sections. As crystals of the mineral have not yet been isolated, it is very difficult to say which particular sections show the unadulterated axis-colours. But I think the following is somewhere near the true pleochroism scheme :—

a = carmine,
b = blue with a lilac tinge, to pale green with a lilac tinge,
c = orange or pinkish orange.

It will be seen that the colours corresponding to the a and b axes are somewhat similar to those of winchite; but the c axis colour is quite different. The extinction angle $a \wedge c$ seems to have a maximum of about 30° in sections showing the a and b axis colours.

Some of the sections showing carmine and shades of green are at right angles to an optic axis, and from the brushes obtained in these sections it seems that the mineral is positive, so that c is the acute bisectrix. I did find ng not succeed in a section accurately at right angles to this bisectrix, but one figure that approached this position seemed to show crossed dispersion, as one would expect if $\bar{b} = c$. One section showing orange and green tints, and hence at right angles to the a axis, was apparently at right angles to the obtuse bisectrix, this also pointing to the positive character of the mineral. In a basal section showing the characteristic cross-cleavages of amphibole, the colour corresponding to the long axis of the cleavage rhombs is pinkish orange to reddish orange (c), and that to the short axis is rich violet, the latter colour being compounded of the a and c axis colours. It seems probable that the mineral is monoclinic and that the c axis coincides exactly with the $\bar{b}$ crystallographic axis, and that the a and b axes lie in the plane of symmetry. But certain anomalies in the behaviour of the mineral suggest the possibility that the mineral may be triclinic approximating closely to monoclinic in the axial angles. This point cannot be settled at present.

Hence we can say provisionally that this mineral is positive, has its plane of optic axial plane at right angles to the plane of symmetry of the mineral, and shows a pleochroism not shown by any other amphibole yet described. The position of the optic axial plane is interesting because with rare exceptions the optic axial plane and plane of symmetry in the members of the amphibole group are coincident. The only two exceptions to this rule mentioned by Iddings in his 'Rock Minerals' (page 345) are crossite from California and a blue amphibole from Viezzena Thal.

It is not yet possible to give any details as to the macroscopic or chemical characters of the mineral, because it has not yet been distinguished in hand-specimens from the blanfordite with which it is associated. But the optical characters of the mineral leave no doubt that it is a new variety of the amphibole group; I propose to name it *juddite* in honour of Professor J. W. Judd, F.R.S., and as a respectful tribute from a former student. It gives me special pleasure to be able to associate the names of Professor Judd and the late Dr. W. T. Blanford with two such beautiful minerals as the amphibole and pyroxene found in this Kácharwáhi rock.

CHAPTER VI.

MINERALOGY—*continued.*

Silicates (*contd.*)—Garnets.

Manganese-garnets—Spessartite—Spandite—Grandite—Aplome—Calderite

Manganese-garnets.

Characters of garnets.

The garnets form a well-marked group of minerals belonging to the holohedral section of the isometric system, the commonest forms being the dodecahedron, trapezohedron (or icosatetrahedron), and hexoctahedron. Cleavage or parting parallel to the dodecahedron, *d*, is sometimes shown, but the mineral usually breaks with a sub-conchoidal to uneven fracture. H.=6·5 - 7·5. G.=3·15 - 4·3. Lustre vitreous to resinous. Colour various shades of red, brown, yellow, green, and black. Streak white. Often show anomalous double refraction. The foregoing characters are taken from Dana's Mineralogy.

Composition of garnets.

In composition the garnets are orthosilicates conforming to the general formula $3R''O.R'''_2O_3.3SiO_2$. They are usually divided into six species according to the bases replacing the R″ and R‴. The R″ may be replaced by Ca, Mg, Fe, and Mn, as main constituents; whilst occasionally alkalies, nickel oxide, and baryta, in small amounts, may enter into the composition of this group. The R_2O_3 group may consist of Al_2O_3, Fe_2O_3, or Cr_2O_3; whilst in very rare cases Y_2O_3 may enter into this group in small amount. Dana does not give any analyses in which Mn enters into the R_2O_3 group; but as will be seen from the analysis of a example of spessartite from Chárgáon in the Central Provinces, it is necessary to assume that in this case at least some of the manganese is in the form Mn_2O_3. The silica is sometimes, though rarely, replaced by TiO_2, and in one case by ZrO_2, to a very small extent.

The names and formulæ of the six recognised species of garnets[1] are as follows :—

Grossularite	$3CaO.Al_2O_3.3SiO_2$
Pyrope	$3MgO.Al_2O_3.3SiO_2$
Almandite	$3FeO.Al_2O_3.3SiO_2$
Spessartite	$3MnO.Al_2O_3.3SiO_2$
Andradite	$3CaO.Fe_2O_3.3SiO_2$
Uvarovite	$3CaO.Cr_2O_3.3SiO_2$

[1] Omitting schorlomite, $3CaO.(Fe, Ti)_2O_3.3(Si, Ti)O_2$.

Isomorphous replacement.

The garnets found in Nature seldom conform exactly to the foregoing formulæ, but are usually found on analysis to be intermediate in composition between two of the ideal species. This is usually ascribed to the isomorphous replacement of the various metals in the protoxide and sesquioxide groups one by the other. Whilst it is convenient to use this term 'isomorphous replacement', it is as well to remember that in all probability this replacement cannot take place within the molecule; but that the phrase really means that there is a molecular mixture of molecules of the same structural formulæ and the same or nearly the same crystalline form. Hence these garnets are best regarded as made up of mixtures of the molecules of two or more of the type garnets in varying proportions. The garnet receives its name according to the predominant molecule.

All the six species of garnets may contain a certain proportion of manganese in the RO group[1]. But in connection with the Indian manganese-garnets it will only be necessary to consider three species, namely, spessartite, andradite, and grossularite.

The published analyses of spessartite often diverge widely from the formula given above. The commonest divergence is for the MnO to be to a considerable extent replaced by FeO, the mineral then gradating towards almandite; and it is obvious that a point may be reached at which it is impossible to decide whether to call the garnet spessartite or almandite. In the same way the Al_2O_3 may be replaced to a considerable extent by Fe_2O_3. No garnet seems to be known conforming to the formula $3MnO.Fe_2O_3.3SiO_2$,[2] so that such a garnet as the above would still be called spessartite. If, however, the replacement of Al_2O_3 by Fe_2O_3 be accompanied by the replacement of MnO by CaO, it is obvious that here also we may have a garnet lying about halfway between two type species, in this case spessartite and andradite. Of the garnets that have been analysed none seem to occupy this intermediate position exactly, there being as a rule little difficulty in grouping them either as spessartite or andradite, although the mineral so called may differ widely from the theoretical composition. To obviate, however, this application of one of these names to a mineral that differs considerably in composition from the typical garnets, special names have sometimes been given; consequently there are

[1] What is really meant in saying this is that mixed with the molecules of all the garnets may be a certain proportion of the molecules corresponding to spessartite.

[2] Unless calderite be really a proper species corresponding to this formula.

several names, for varieties of garnets, that have no very explicit meaning and can usually only be applied to the garnet of the particular locality for which the term was invented. If any one need a name for a garnet that he has analysed and finds to depart considerably from any of the type formulæ, he cannot as a rule use any of the existing varietal names, but is under the necessity of inventing another and increasing still further the number of these indefinite varietal names. There is a very simple way out of this difficulty, which would, if adopted, do away with the necessity for all these names. This consists in forming compound names expressing the position of a given garnet between two of the type species. Thus there is a garnet to which the name *polyadelphite* has been given. According to analysis 19 on page 443 of Dana's Mineralogy this garnet can be fairly regarded as a variety of andradite in which a certain proportion of the CaO is replaced by MnO. Analysis 20 of another specimen of polyadelphite from the same locality, namely Franklin Furnace, N.J., U.S.A., contains, however, a much larger proportion of MnO replacing the CaO, whilst there is also a considerable proportion of Al_2O_3 replacing the Fe_2O_3. Although the garnet is still closer in composition to andradite than to spessartite, yet it differs considerably from the typical andradite and is in fact not so very far removed from being half-way in composition between these two garnets. Instead of having a special name, polyadelphite, for this garnet it would be better to call it *spessart-andradite*, expressing the fact that it is really a compound of these two garnets. This could for brevity's sake be contracted to *spandite*. If reference be made to the analyses[1] given in columns 3 and 4, on page 168, it will be seen that there is a considerable difference between the composition of the two garnets from the Vizagapatam District that these analyses represent.

Origin of the term 'spandite'.

The Garbhám garnet has the RO group composed about equally of CaO and MnO and in this respect is about half-way between spessartite and andradite. In the R_2O_3 group, however, the Fe_2O_3 is much larger in amount than the Al_2O_3, so that in this respect the garnet is fairly close to andradite in composition. It might then be thought that this garnet could be called a *manganese-andradite*. The Kotakarra garnet also

1 One of these is an actual analysis of the mineral, and the other calculated from the analysis of the rock in which it occurs.

shows that the CaO and MnO are about equal in amount, but in the R_2O_3 group, the Fe_2O_3, instead of being the predominant oxide, is very small in amount, so that nearly the whole of the group consists of Al_2O_3. In the same way, then, this garnet could be called *calcium-spessartite*. The two garnets are, however, indistinguishable in appearance, and both occur in the same series of rocks, namely the kodurite series. And if one were to go by the fact that they both react strongly for manganese one would call them both spessartite, this being *par excellence* the manganese-garnet. This in fact is what has been done in the previously published accounts of the manganese-ore occurrences of this district [1], the garnet reacting for manganese and resembling very closely in colour some varieties of spessartite from the Central Provinces. I propose, therefore, to obviate this difficulty by the use of the term *spandite* for the manganese-garnets of the Vigazapatam district; any garnet from the manganese-bearing rocks of this area that gives a strong reaction for manganese will be included provisionally under this term. If, however, the term spandite be considered objectionable, then in view of what we know of the composition of these garnets there is no alternative to calling them *manganese-garnet*. The awkwardness of such a term is seen when it is desired to designate a rock by the names of its mineral constituents. Thus kodurite would be apatite-manganese-garnet-felspar-rock. In this form it looks as if the rock contained four constituents, namely apatite, manganese, garnet, and felspar. This is particularly objectionable because amongst the mining community manganese-ore is frequently spoken of as manganese, *manganese* thus meaning in the loose parlance of the mining areas the mineral containing the element manganese rather than the element manganese itself. Hence in the foregoing example a mining man might understand that the rock was composed of apatite, manganese-ore, garnet, and felspar.

Use of the term 'spessartite'.

On page 168, analyses are also given of two manganese-garnets from the gondite series of the Central Provinces. It will be seen that in both cases the group RO consists to a predominant extent of MnO, the lime being small in amount, so that from this point of view the garnets are to be regarded as spessartite rather than manganesian varieties of andradite. In the Wagora garnet the R_2O_3 group is all Al_2O_3, so that there can be no hesitation in calling this mineral spessartite. In fact this garnet, owing to the presence of nearly 10 per cent. of FeO as part of the RO

[1] *Rec. G. S. I.*, XXXII, p. 96, (1906);
Trans. Min. Geol. Inst. Ind., I, p. 87, (1906).

group, shows affinities to almandite rather than to andradite. In the Chárgáon garnet, on the other hand, it will be seen that the R_2O_3 group is composed of about equal parts of Al_2O_3, Fe_2O_3, and Mn_2O_3. In this respect it diverges considerably from spessartite. It is, however, very far removed from andradite, so that again there is no alternative to calling it spessartite; unless one invents a special name for a garnet conforming to the formula $3MnO.Mn_2O_3.3SiO_2$, this not being one of the six type garnets referred to on page 161. If such were done, we could say that the Chárgáon garnet was intermediate between spessartite and this other type. Such a course is undesirable and consequently I have also called this garnet spessartite. I have, therefore, relying on these two analyses, used the term spessartite for all the manganese-garnets found in the rocks of the gondite series wherever they occur, namely in the Central Provinces, in Central India, and in Nárukot; especially since, as far as one can tell from outward appearance, they are all the same in mode of occurrence, crystalline habit, and the fact that they react strongly for manganese. The differences of colour that they exhibit are to be explained by the replacement of the manganese by iron and other elements to a varying extent and by the replacement of the Al_2O_3 by varying amounts of Fe_2O_3 and sometimes Mn_2O_3.

Origin of the term 'grandite'.

If reference be made to the analysis of a manganese-garnet from Boiráni in Ganjám, given in the fifth column on page 168, it will be seen that this garnet, which outwardly resembles some varieties of spessartite from the Central Provinces, is practically a variety of grossularite, $3CaO.Al_2O_3.3SiO_2$, with a small amount of manganese replacing a portion of the lime in the RO group, and with nearly half the Al_2O_3 replaced by Fe_2O_3. But as the RO group of andradite also consists of CaO it is obvious that this garnet can be regarded almost equally well as a variety of andradite with a little over half its Fe_2O_3 replaced by Al_2O_3. This garnet might therefore be equally well designated iron-grossularite or aluminium-andradite, not considering for the present the small quantity of MnO present. To get over this difficulty, the mineral may very well be called, on the principle explained above, *grossular-andradite*, or for short *grandite*. If it be desired to express the fact that manganese is also present—this after all being the most important constituent from the economic point of view, as it is this that gives rise to the manganese-ores of Boiráni—the garnet can be called *manganese-grandite*. From the point of view of brevity this term has of course no advantage over the term manganese-garnet and the term

'manganese-grandite' is open to the same objections, when it is necessary to use it in compound names of rocks, as 'manganese-garnet' is (see page 164). The difficulty cannot always be obviated, as in the present case, unless the mineral be called grandite without the prefix manganese'. The advantage of the term manganese-grandite lies, of course, in its explicitness.

In view of what has been written above I propose to refer to the manganese-garnets of the different areas in India as:—

1. *Spessartite;* in the rocks of the gondite series, *i.e.*, in the Central Provinces, Jhábua, and Nárukot.

2. *Spandite;* in the rocks of the kodurite series in the Vizagapatam district.

3. *Manganese-grandite*, or more briefly *grandite*; in the rocks, allied to the kodurite series, of the Ganjám district.

4. *Aplome;* a special variety (see page 182).

5. *Calderite;* in the massive garnet-rock of Házáribágh (see page 182).

6. *Manganese-garnet;* in cases of considerable doubt as in pegmatites in the Central Provinces, where the character of the garnet has not been investigated, or in cases in which the mineral does not give a very marked reaction for manganese; also sometimes in referring to any of the other garnets, to avoid the monotony in the constant repetition of the terms spessartite and spandite.

Analyses of Indian manganese-garnets.

I will now give below the analyses that have been made of Indian manganese-garnets. They are only two in number. The first was prepared for analysis by Mr. J. Coggin Brown by breaking up two or three trapezohedral crystals of spessartite from Chárgáon in the Nágpur district, and carefully picking out those fragments that showed no trace of oxy-alteration, the crystals being always altered to a certain extent along cracks. The specific gravity was determined on the picked material, but the figures were unfortunately lost. Specimens of garnet from this locality, however, usually give values for this constant ranging from 4·15 to 4·2 or a little over. The analysis was carried out by Mr. T. R. Blyth, the amount of material available for this purpose being not more than ½ a gramme, so that it was not possible to determine the state of oxidation of the manganese. The second also was picked for analysis by Mr. Brown, who also carried out the analysis. The rock from which the garnet was obtained was a specimen of spandite-rock from the Garbhám mine in the Vizagapatam district, Madras. The material separated had a rich red colour and specific gravity as determined

by Penfield's method of 4·02. Again the state of oxidation was not determined. The two analyses are given below :—

	Spessartite.	Spandite.
	Chárgáon. *Specimen No. 1030.*	Garbhám. *Specimen No. A. 219.*
SiO_2	34·71	35·24
Al_2O_3	8·05	6·48
Fe_2O_3	8·38	23·90
MnO	38·83	16·37
MgO	5·40	2·04
CaO	4·97	15·20
BaO	Trace	0·18
TiO_2	...	*Nil*
Moisture at 100° C.	*Nil*	*Nil*
Combined water	Undet.	Undet.
	100·34	99·41

The analyses are given above as returned by the analysts. Since the state of oxidation had not been determined, I calculated the foregoing analyses into terms of the general formula $3RO.R_2O_3.3SiO_2$, assuming the state of oxidation required for the constituents of the analysis to agree with this formula. The analyses thus re-arranged are given in the table on the next page. It will be seen that in the case of the Chárgáon garnet it was found necessary to add on 0·96 % of oxygen so as convert a portion of the MnO into Mn_2O_3, whilst an excess of 3·00 % of MgO above the amount of constituents required for the protoxide group has been excluded from the re-arranged analysis. In the case of the Garbhám garnet it was found necessary to add 0·26 % of SiO_2, and to reject 0·27 % of oxygen, because a small portion of the Fe_2O_3 had to be converted into FeO for the protoxide group. The interesting features of these analyses are first the presence of BaO in one case in traces and in the other to the extent of 0·18 %, and secondly the existence, as deduced by calculation, of Mn_2O_3 in the R_2O_3 group in the Chárgáon garnet, it being usually thought that all the manganese in garnets is present in the form of MnO. On pages 349 and 257 will be found analyses of gondite from Wagora in the Chhindwára district, Central Provinces, of opalized kodurite from Kotakarra in the Vizagapatam district, Madras, and of opalized kodurite from Boiráni in the Ganjám district, Madras ; and further, an analysis of the garnet contained in each rock deduced by calculation from each rock analysis. These 5 garnet analyses, all calculated to 100, are given below. Their composition has already been discussed in connection with the nomenclature of the manganese-garnets on the preceding pages.

TABLE 17.

Analyses of Indian manganese-garnets.

—	1	2	3	4	5
Locality	Chárgáon	Wagora	Garbhám	Kotakarra	Boiráni
Number	1030	16/984	A. 219	A. 233	A. 134
Specific gravity.		4·24*	4·02		3·76*
MnO	30·81	24·48	16·46	16·50	2·68
FeO	..	9·94	2·49	7·45	2·16
CaO	5·06	3·11	15·29	15·80	30·70
MgO	2·44	3·48	2·05	0·23	0·65
B_2O	..	..	0·18	..	..
Al_2O_3	8·19	21·26	6·52	18·98	14·22
Fe_2O_3	8·52	..	21·28	3·47	11·41
Mn_2O_3	9·67	..	..	..	..
SiO_2	35·31	37·73	35·73	37·57	38·18
	100·00	100·00	100·00	100·00	100·00
Manganese	30·59	18·95	12·75	12·77	2·08
Iron	5·96	7·73	16·84	8·22	9·67

Nos. 1 and 2 = spessartite; from gondite series, Central Provinces.
Nos. 3 and 4 = spandite; from kodurite series, Vizagapatam
No. 5 = manganese-grandite; from kodurite series, Ganjám.
Nos. 1 and 3 are from actual analyses of garnets, and Nos. 2, 4 and 5 calculated from analyses of rocks containing them.

We can now consider the Indian manganese-garnets under the headings of spessartite, spandite, grandite, aplome and calderite.

Spessartite.

Occurrence of spessartite.

On the strength of two analyses, I am, as explained above, provisionally calling all the garnets found in the gondite series, *i.e.*, in the manganese-bearing rocks of the Central Provinces, Jhábua, and Nárukot, by the

*Calculated.

name of spessartite. In the Museum there are also some specimens of spessartite from Kulu, presented by Colonel G. Gordon Young. They are stated to have been found in mica-schist. Apart from this the only yet recognized occurrences of this mineral in India are in the gondite series in the areas mentioned above. As this is the characteristic mineral of this series of rocks it is to be found in nearly all the varieties of the gondite series, a list of the rocks of which will be found on page 329; it is to be understood that spessartite occurs in all those in the name of which the word gondite occurs, as well as in those rocks in the name of which it is explicitly mentioned. The typical occurrence is of course in the rock known as gondite, this being composed of spessartite and quartz. Frequently the rock is very fine-grained so that the individual garnets are not to be distinguished by the naked eye, but only with a lens, or in some cases only in thin sections under the microscope. On the other hand, the rock is often sufficiently coarse-grained for the crystalline form to be easily visible to the naked eye, the crystals being sometimes so large that they would have a diameter of one or even two inches across if they were whole. It is not necessary to give a list of all the localities for this mineral since it is found in nearly all the deposits associated with the gondite series; and lists of these deposits in the districts of Bálághát, Bhandára, Chhindwára, and Nágpur, in the Central Provinces are given on pages 695, 735, 772, and 841. The only other localities are Kájlidongri in Jhábua, and Jothvád in Nárukot, and the above-mentioned Kulu occurrence. By turning up the description of any particular deposit it will be found if spessartite occur at that particular place or not. At a few of these deposits spessartite has not yet been detected; as, for example, at Sitapár in the Chhindwára district.

Abundance and economic importance of spessartite.

It will be as well to emphasize here the enormous importance of this mineral from the economic point of view. As shown on pages 293 and 353, a considerable proportion of the manganese-ores of the gondite areas has been derived from this mineral by chemical alteration. The consequence is that in the course of quarrying the manganese-ores large quantities of gondite and other rocks of this series are found in every stage of alteration into manganese-ore. The quantity of such rock in either the fresh condition or partly altered to manganese-ore is enormous, and the quantity of spessartite being thrown on to the dumps every year must run into thousands, if not into hundreds of thousands, of tons. I am not mentioning this as a fact to be regretted; for spessartite is at present a valueless mineral, although it often contains 20

to 30 per cent. of manganese. I merely mention the fact to emphasize what enormous quantities of this mineral exist in association with the manganese-ores of the Central Provinces. The importance of it to the mining man is as a prospecting indication. For if he find a piece of spessartite, or rock containing it, he should look for its source; for it may lead to the discovery of a body of manganese-ore with which it was associated. Although such enormous quantities of spessartite exist in India, it is a rare mineral in most other countries, except in small quantities. There are, however, a few localities outside India where it is to be found in fair abundance, as for example in the manganese-ore deposits of the Queluz area, Brazil, and the spessartiferous rocks of Texas. The formation of the Indian mineral by the metamorphism of manganiferous sediments of Dhárwár age is fully discussed on pages 288—292.

Localities for good crystals.

When this mineral is found in coarse-grained rocks it usually shows more or less perfect crystals. Although I have not given above a list of localities for this mineral in India, I will give here the names of the localities at which the best crystals are to be found. They are:—

Nárukot State:—
Jothvád.
Bhandára district:—
Hatora.
Chhindwára district:—
Bichua and Gaimukh.
Nágpur district:—
Chárgáon, Sátak, and Wáregáon.
Kulu.

At *Jothvád* a band of spessartite-quartz-rock of coarse grain was found. On the weathered surface the garnets were seen to be orange-red and joined together in parallel growth. The crystal form is the rhomb-dodecahedron, often distorted by growth along one axis into prismatic forms.

At *Hatora* spessartite trapezohedra up to $\frac{1}{2}$ inch diameter are found in amphibole-gondite. The crystals sometimes show minute hexoctahedral faces.

At *Bichua* the garnet occurs in a pegmatite composed of white quartz and a white felspar lying between albite and oligoclase. The garnet where fresh is orange-red in colour, but sometimes dull brown-black due to alteration. The rock is intrusive into the gondite series. It is therefore not certain, though very probable, that this garnet is spessartite, for the

Photo. by H. B. W. Garrick. *Calcutta Phototype Co.*

SPESSARTITE CRYSTALS (TRAPEZOHEDRA) WITH INTERSTITIAL QUARTZ, ON A BASIS OF MANGANESE-ORE. FROM WAREGÁON, NÁGPUR DISTRICT. NATURAL SIZE.

reason that no analysis has yet been made of manganese-garnets in such pegmatites. The crystals are trapezohedral in form and if complete would often be 1 to 2 inches in diameter. One piece gave a value for G of 4·02, which is rather low for this mineral, although within the limits (see fig. 13).

At *Gaimukh* the mineral is found in a rock containing a certain amount of quartz and rhodonite, with spessartite as the chief mineral. It occurs in beautiful trapezohedral crystals up $\frac{1}{4}$ inch in diameter, the smaller crystals being a beautiful deep orange-red in colour, and the larger ones blackish.

The best locality of all is the pit known as the Kámthi Lady Pit, situated at the eastern end of the *Chárgáon* portion of the Mansar deposit. The occurrence is described on page 883. The garnets are often most beautiful trapezohedra, sometimes exhibiting all 24 faces, which are usually striated parallel to the faces of the dodecahedron. Fig. 14 on page 172 represents a garnet from Chárgáon. Other faces to be noticed below are also sometimes seen.

At *Sátak* the garnets occur in garnet-rhodonite-rock very similar to that of Chárgáon. They show trapezohedral faces, and if whole some of them would be $1\frac{1}{4}$ inches in diameter. The colour is yellowish black. Good crystals are also found in amphibole-gondite, although in this case they are smaller. At *Waregáon* I have obtained a considerable number of fine specimens of this mineral. Indeed, after Chárgáon, it is the best locality; but on account of the abandonment of the quarry, which is now filled with water, it is doubtful if any more specimens could be obtained, except by searching the dumps. These specimens consist partly of spessartite-rock and partly of spessartite-quartz-rock, the latter being the more favourable for the development of good crystals. The latter are, as usual, trapezohedra, occasionally showing dodecahedral and hexoctahedral faces. Some of them if whole would be $1\frac{1}{2}$ to 2 inches in diameter. In colour they vary from deep orange-red to chocolate-brown, the latter being due to alteration (see figures 13, 15, 17, 18, 19 and Plate 7).

The *Kulu* garnets are practically perfect dodecahedra up to nearly $\frac{1}{2}$ inch in diameter and of a deep brown-red colour when whole. The specific gravities of two of them were found to be 4·11 and 4·16, respectively. That they are spessartite was confirmed by Babu Kiran Kumar Sengupta, who found one of them to consist almost entirely of silica and oxides of iron, manganese, and alumina (see fig. 16).

It must not, however, be imagined that the above are the only localities at which good crystals are to be found. I have myself also found them at several other localities; whilst Mr. E. L. Young showed me a large number of specimens of trapezohedral crystals obtained at the Lohdongri mine, Nágpur district, and Mr. C. E. Low has found good crystals of unusual form in Government Forest about one mile west of Kudsuri village in the Bálághát district.

Crystallographic character.

As will be judged from the above, the crystalline habit of this mineral is characteristically trapezohedral (or icosatetrahedral), usually without any modifying faces (see fig. 13). The faces of the trapezohedron are, however, usually striated with a delicate series of lines, which are parallel both to the faces of the dodecahedron and to certain of the edges of the hexoctahedron. This is well illustrated by fig. 14, which represents a crystal of this mineral from Chárgáon. It is the best crystal of this mineral I have found and is

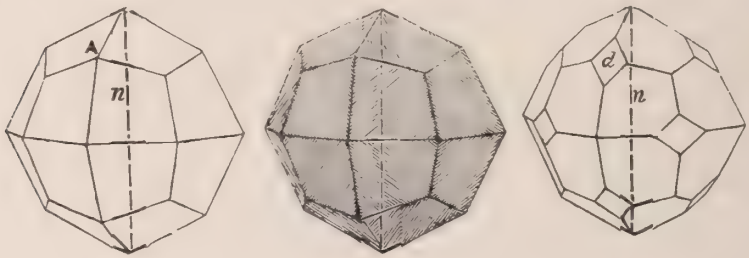

Fig. 13. Fig. 14. Fig. 15.

Spessartite Crystals.

Fig. 13.—Trapezohedron; Bichua and Waregáon.
Fig. 14.—Striated trapezohedron; Chargáon.
Fig. 15.—Trapezohedron and dodecahedron; Waregáon.

nearly $\frac{3}{4}$ inch in diameter, showing all twenty-four faces of the trapezohedron. Another almost equally perfect crystal from the same place is $\frac{1}{2}$ inch in diameter. Sometimes, but only rarely, the corner A of the trapezohedral crystal is modified by the presence of the faces of the dodecahedron, *d*, or (110), as in fig. 15. These are usually small in proportion to the size of the trapezohedral faces, but in one case I found a manganese-garnet in which the latter faces were absent, the crystal being a simple dodecahedron (see fig. 16). This was in a pegmatite composed of quartz, felspar, pale sea-green mica, and manganese-garnet, occurring near Kachi Dhána, Chhindwára district. The garnet is of reddish brown colour, but on account of its mode of occurrence it is not known

whether this manganese-garnet is to be referred to spessartite. The Kulu garnets are, however, all dodecahedra without any modifying faces. The Jothvád spessartite noted on page 170 is also dodecahedral. In a few cases the corner A of the trapezohedron in spessartite is modified by the presence of the four faces of the hexoctahedron, *s* or (321), usually very small (see fig. 17). The garnets showing these faces are

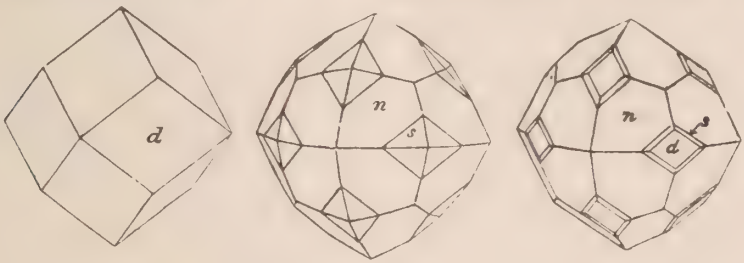

Fig. 16. Fig. 17. Fig. 18.

Spessartite Crystals.

Fig. 16.—Dodecahedron : Kulu and Kachi Dhána.
Fig. 17.—Trapezohedron and hexoctahedron : Bhui Hurki and Waregáon.
Fig. 18.—Trapezohedron, dodecahedron, and hexoctahedron : Waregáon.

from Waregáon and Mándri in the Nágpur district, from Hatora in the Bhandára district, and from Bhui Hurki in the Bálághát district. The best examples of hexoctahedral faces are seen on some small orange trapezohedra on a specimen brought by Mr. A. Whyte from Bhui Hurki. The Waregáon crystals sometimes show the faces of the dodecahedron with the hexoctahedral faces bevelling the edges between the *n* and *d* faces, as in figure 18. According to Dana octahedral faces are very rarely

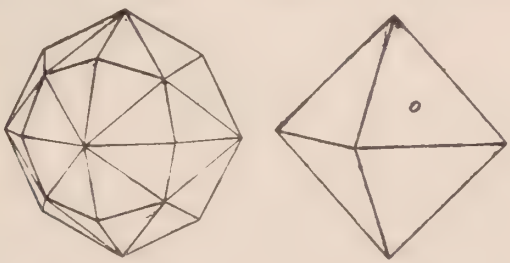

Fig. 19. Fig. 20.

Spessartite Crystals.

Fig. 19.—Trapezohedron composed of vicinal hexoctahedral faces ; Waregáon.
Fig. 20.—Octahedron.

observed on garnets. I have not yet found any on Indian garnets.[1] Some crystals of a manganese-garnet of dark orange-brown to dark brown colour, up to $\frac{1}{2}$ inch in diameter, and set in a matrix of quartz, were obtained by Mr. C. E. Low from near Kudsuri in the Bálághát district. Some of these crystals show a combination of the trapezohedron and dodecahedron, the two forms being about equally developed, whilst some show trapezohedral faces only. The garnet reacts for manganese, but it is not yet known if the mineral is to be referred to spessartite.

From what has been written above it will be seen that the commonest, and in fact the characteristic, form of this mineral is the trapezohedron, *n*, or (211); whilst faces of the rhomb-dodecahedron, *d*, or (110), and of the hexoctahedron, *s*, or (321), are not uncommonly found. I have seen no twinned crystals of Indian manganese-garnets.

One trapezohedral crystal obtained from Waregáon shows that a few of its faces are really made up of vicinal hexoctahedral faces, one trapezohedral face being composed of two very flat hexoctahedral faces, as in figure 19.

The crystals are usually about equally developed along all three axes; but occasionally they are distorted. Thus the dodecahedral crystals of Jothvád (see page 170) tend to be prismatic. A crystal from Waregáon is very flat owing to being much more developed along two of the axes than the third. This crystal, also, indicates that the trapezohedral faces are composed of vicinal hexoctahedral ones.

Cleavage.

In one case I have noticed under the microscope what seems to be well marked cleavage, evidently parallel to the faces of the rhomb-dodecahedron, *d*; for these cleavages made angles of 60° with each other. The specimen in which this phenomenon was noticed was a piece of gondite from the Kájlidongri mine, Jhábua State. The fracture of spessartite is very variable. Sometimes it is sub-conchoidal, especially on unaltered examples. At other times it is irregular or uneven.

[1] In one specimen—a piece of rock from Chárgáon showing trapezohepdral crystals of spessartite set in a matrix of rhodonite, barytes, and a green phosphate—I thought I had found an embedded octahedron of spessartite, with one corner, showing four faces, projecting. Hence the insertion of fig. 20. Later, feeling doubtful, I broke up the specimen and found the supposed octahedron to be a trapezohedron, with the top corner (as oriented in fig. 13) projecting.

Structure zoning.

Very frequently the mineral breaks so as to show a zoned surface. This is found to be, not a true fracture, but usually the surface of contact with another crystal, the two having mutually stopped each other's growth at the surfaces where they meet. These zoned surfaces are also often found at the contact of an imperfectly developed crystal with the quartz in which it is found. It is only with difficulty that this zoning can be obtained on a true fracture surface. When it is carefully examined it is seen to be due to a layered structure of the garnet parallel to the faces of the trapezohedron. This seems at first sight surprising because the striations so often seen on the faces of the trapezohedron, make it look as if the mineral were composed of lamellæ parallel to the faces of dodecahedron, *d*.

Striations.

The case noted on page 174 of a crystal with its trapezohedral faces composed each of two vicinal hexoctahedral faces suggests, however, that the striations often observed on the trapezohedral faces of the Indian spessartites may really indicate an oscillatory combination with the hexoctahedron rather than with the dodecahedron. The striations are parallel both to certain of the edges of the hexoctahedron and to all the faces of the dodecahedron. The hexoctahedral interpretation agrees with the zoning.

Specific gravity.

I have not particularly tested the hardness of the mineral; but it seems to agree with the values given in the text-books. The specific gravity of spessartite is given as 4·0 to 4·3 and I find that the few I have tested lie within these limits, tending to be from 4·15 to 4·25. The following show the actual values that have been determined for Indian spessartites :—

Bichua	4·02.
Chárgáon (figured)	4·16.
Kulu	4·11 and 4·16.

Colour.

This mineral exhibits considerable variety of colour. It is not very often that the crystals are perfectly transparent and free from darkening due to alteration; but when the crystals are in this condition they are often of a most beautiful bright orange colour, and if they could be obtained in quantity and of a fair size they might be used as a most lovely gem. Frequently the colour is considerably darker than this, being then usually orange-red, the tint of which is often exactly the same as that of ordinary guava jelly. More rarely the colour is even

darker, being occasionally almost blood-red. In one case at Hatora I found a specimen showing a layer of this garnet resting on manganese-ore. The spessartite was of a colour that almost exactly matched that of crystals of potassium bichromate. Of the colours mentioned above the pure orange and the guava-jelly colour are about equally common, there being of course every gradation from one into the other. When the crystals are darkened due to alteration, the result is usually to give rise to deep reddish black colours, as in the crystal of garnet from Chárgáon shown in figure 14. This is simply the result of the darkening of the true orange or orange-red of the unaltered mineral, owing to the presence in it of black oxides of manganese. Such crystals when boiled in hydrochloric acid so as to remove the oxides often assume a bright orange colour. Sometimes, however, the colour is a dark chocolate-brown due to the fact that the mineral has become very much altered throughout its substance; when it has reached this condition the garnet is usually fairly soft and easily scratched with a knife. Occasionally large crystals are yellow in colour, as at Sátak; this is not, however, the colour seen through a good thickness of the transparent mineral, but only that seen through a small thickness at the surface, the underlying portions being altered. Since an orange mineral when seen in thin layers would appear to be yellow, it is probable that if this example from Sátak were fresh and unaltered, so that one could look into it through a good thickness of the mineral, it would also appear to be of an orange or orange-red colour. The colours as given above are only those observed on crystals large enough to handle conveniently, *i.e.*, not smaller than $\frac{1}{8}$ inch in diameter. But as seen in the fine-grained rocks containing this mineral the colour is often much paler, such as sulphur-yellow, pale yellow, cinnamon, and even greyish. Under the microscope also there is seen to be a great variation in the colour of spessartite. I should say that the most characteristic colour as seen thus is a light yellow; but sometimes the colour is as dark as bright sulphur-yellow, or so pale that the mineral is practically colourless, although the latter form is rare. In rarer cases the mineral shows some shade of brown in the yellow, and occasionally the colour is sufficiently dark to be called light orange. In very rare cases the mineral shows a distinct pink tint, but in such a case it may perhaps be doubted if the mineral is truely to be regarded as spessartite. A case in point is that of a manganese-garnet in gondite from Bichua. In the hand-specimen the mineral is of an orange-red colour, whilst under the microscope it is a salmon-pink.

This variation in the colour of spessartite, both in the hand-specimen and under the microscope, is very interesting, as it points to a great variation in the composition of the mineral. It would be very interesting to analyse a series of specimens of this mineral to find out what is the connection between the colour and composition. It would probably be found that the main factors in producing this variation in colour are the relative amounts of manganese and iron. It is further interesting to note that not only does the colour of this mineral vary from one crystal to another, but that often there is a great variation between the colour of the outer and inner zones of the same crystal. I have not actually noticed this macroscopically, but it is a common phenomenon under the microscope. Thus the pink example from Bichua referred to above is nearly colourless in the centre; whilst in a specimen of gondite from Kodegáon, the garnets are sometimes sulphur-yellow throughout, and some times colourless in the centre and yellow on the outside, this latter phenomenon being very frequently observed. In an example from Jothvád the mineral is yellow and light brown in patches, tending to be yellow towards the centre. Another cause of variation in the colour of spessartite is inclusions. The normal colour of a piece of typical gondite, *i.e.*, the fine-grained rock composed of spessartite and quartz, is a fairly light colour, especially some shade of yellow, cinnamon, or grey. But sometimes the rock shows purplish or reddish tints, as in cases from Hatora and Ukua. Under the microscope this colour is found to be due to the presence in the centre of each garnet grain of a cloud of very finely divided red dust, which is probably ferric oxide or hematite. Such rocks are often banded, some layers being reddish or purplish due to the presence of these inclusions, and some of them of the normal light colour of gondite, the garnets in such layers being found under the microscope to be free from the inclusions found in the other bands. In some of the Chárgáon garnets definite inclusions of red hematite are seen under the microscope, as well as brown films, perhaps of limonite; the hematite inclusions were probably formed at the same time as the garnet, and probably express the fact that there was a small surplus of ferric oxide over that required for the formation of the garnet. The limonite films, on the other hand, occupy cracks, and, presumably, were introduced subsequent to the formation of the garnet. Hematite also occurs in patches in spessartite in gondite from Kájlidongri. Spessartite is sometimes quite free from inclusions; but it more often contains them, either of the kind noticed above, or of other kinds.

Colour zoning.

Inclusions.

One of the commonest of these is a colourless highly refracting mineral, which is probably apatite. Black inclusions are also sometimes present. These may represent a residue of manganese oxide over that required for the formation of the garnet, similar to the case of the hematite inclusions mentioned above.

Anomalous double refraction.

Spessartite, belonging to the isometric or cubic system like all the garnets, should be isotropic, *i.e.*, remain dark as viewed between crossed nicols during a complete revolution under the microscope. Many garnets, however, exhibit anomalous double refraction, and the Indian spessartites are no exception in this respect. This phenomenon, which is considered to be of secondary origin, is most often seen in the spessartite of Kájlidongri, and causes the part of the crystal exhibiting it to polarize in a very low grey, in which there may be a yellowish tinge owing to the superposition on it of the yellow colour of the garnet. The whole of the spessartite is sometimes affected by this phenomenon, the garnet then being split up into small areas of different optic orientation as if it were an aggregate of different individuals. In places it shows signs of interference crosses, which in some cases are very distinct. In one case where the garnet was zoned, colourless inside and yellow outside, the colourless portions showed anomalous double refraction to a much less marked degree than the yellow portions.

Microscopic aspect.

Of the characters of this mineral observable under the microscope in thin sections, the colour and anomalous double refraction have already been discussed. The other noticeable features are :—the high index of refraction, causing the mineral to stand up in the sections and to exhibit very pitted surfaces; and the great tendency to idiomorphism that it displays. When the whole rock is composed of spessartite, the separate garnets mutually interfere with each other; but when there is another mineral, such as quartz, to act as a cement to the garnet, the latter shows its crystal outlines, which are usually polygonal. The garnets are then about equally developed in all directions and are doubtless almost always the cross sections of trapezohedra. When rhodonite is present the garnet is almost invariably idiomorphic with regard to the rhodonite in which it is often enclosed. Occasionally, however, the relation of these two minerals is reversed. In one case, namely in a rock from Kájlidongri, the garnet seems to have been formed later than the quartz; for it includes the latter, so that the garnet forms the meshes of a net

surrounding the separate grains of quartz. The alteration of this mineral is discussed on another page (354), and is illustrated by figures 1 and 2 on Plate 12; whilst the form of the mineral as viewed under the microscope is illustrated by figures 1 to 3 of Plate 11.

Spandite.

Composition.

As already explained (page 163), 'spandite' is a name proposed for the varieties of manganese-garnet that are intermediate in position, as regards composition, between spessartite and andradite. An ideal specimen of spandite would contain about equal proportions of manganese and calcium in the protoxide group and about equal proportions of iron and aluminium in the sesquioxide group. Analyses are given on page 168 of two specimens of spandite from the Vizagapatam district, and since these are considered to be representative of the whole of the manganese-garnets occurring in the kodurite series of this district, I propose to designate all the manganese-garnets found in this series by this name. At present, moreover, no analyses of manganese-garnets have been made that justify the application of this name to manganese-garnets outside this district. Consequently the mode of occurrence of this variety of garnet will be best understood by reading the account of the kodurite series given on pages 243—255. The characteristic rock in which this mineral

Occurrence.

is found is the one I have designated *kodurite*. This consists of potash-felspar, apatite, and spandite. Often quartz is present as well, the rock then being quartz-kodurite; whilst sometimes the garnet forms practically the whole of the rock, which is then known as spandite-rock. The best locality for spandite-rock is Kodur. As explained on page 247, the rocks of this series are supposed to be of igneous origin, and as the spandite is considered to be an original mineral, this origin must also be ascribed to it. Not only is it found in the rocks of the kodurite series, but it is frequently present in the ores that have been formed during the chemical changes that have affected the rocks of this series since their formation, with the production of merchantable manganese-ores. In these cases it often appears as bright red garnets set in a matrix of manganese-ore, usually psilomelane. On Plate 8, fig. 4, is a photo-micrograph of such ore, showing the psilomelane growing at the expense of the garnet. The best localities for such specimens are Garbhám and Rámabhadrapuram (Mámidipilli). The following is a list of the

localities at which manganese-garnet has been found in this district :—

Ávagudem, Chintelavalsa, Devádа, Kantikapilli, Kodur, Kotakarra, Garbhám, Mámidipilli, Perapi, Sandapuram, and Táduru.

If this list be compared with the list given on page 1047, of localities at which manganese-ore is found in this district, it will be seen that there are some localities at which spandite has not yet been found. This is probably only on account of the deposits not having been sufficiently opened up. Later on this garnet will doubtless be found in all these deposits, except ones that are purely detrital, such as Garividi.

Characters.

Probably owing to its igneous origin, from which one would expect a greater uniformity of composition and consequently a greater constancy of physical characters than in garnets of metamorphic origin, this mineral is much less variable than the spessartite of the Central Provinces. In size it is fairly uniform, seldom ranging outside the limits of $\frac{1}{16}$ and $\frac{1}{4}$ inch in diameter. In spandite-rock, *e.g.*, at Kodur, it occurs in granules averaging $\frac{1}{8}$ to $\frac{1}{4}$ inch across. In this rock the granules are all pressed one against the other, so that they are bounded by flattish faces that do not, except perhaps occasionally by accident, conform to any particular crystallographic direction. In kodurite the spandite individuals, which are usually about $\frac{1}{16}$ to $\frac{1}{8}$ inch in diameter, are found both aggregated and as separate granules. These granules are either well rounded, or are partly bounded by small unrecognizable faces. They often show brilliant reflections both from the faces mentioned above and from fractures, the lustre being vitreous in the former case and resinous in the latter. The spandite varies in rocks from different localities from deep orange to orange-brown, orange-red, and blood-red, and never shows the yellow and lighter orange colours of the spessartite of the Central Provinces. Under the microscope these garnets show various tints of pale yellow, pale orange, and pale orange-brown, a brownish tint being much more often seen in spandite than in spessartite. One mineral with which it may easily be confounded is the pyroxene mentioned on page 137, found in the manganese-pyroxenites. It is often impossible to determine without recourse to the microscope whether a particular grain in one of these rocks is a garnet or a pyroxene, so similar are they in their size, indefinite form, and orange-brown colour.

The specific gravity of this mineral is considerably lower than that of spessartite, lying, as might be expected, between that of spessartite and that of andradite. The specific gravity of spessartite is given by Dana as 4·0 to 4·3, and that of andradite as 3·8 to 3·9. The one actual determination of the specific gravity of spandite is that of the specimen from Garbhám of which the analysis is given on page 168. This value is 4·02.

The alteration of this mineral is considered on pages 265—6; and is illustrated by fig. 4 of Plate 8. The figures 1 to 4 of Plate 8 illustrate the occurrence of this mineral. The minerals with which it is associated at various localities can be seen from the account of the minerals of the kodurite series given on pages 250—3.

Grandite.

As explained on page 165, this name has been proposed for those garnets intermediate in composition between grossularite and andradite, so that the typical grandite would have its RO or protoxide group composed entirely of CaO, and its R_2O_3 or sesquioxide group of about equal amounts of Al_2O_3 and Fe_2O_3. An analysis of an Indian garnet corresponding very closely to this ideal composition is given on page 168. It also contains a small amount of MnO, namely 2·68%. This amount of one constituent would, as a rule, be insufficient to require noticing in the name of a garnet. It so happens, however, that this is the most important constituent of this particular garnet, because it is from this small amount of manganese that the associated manganese-ores have been derived. Hence this mineral can be called *manganese-grandite*. But I shall refer to it merely as grandite. It is found at Boiráni in the Ganjám district, in a rock composed, when fresh, of orthoclase-felspar, garnet, and a little apatite, the latter being only visible under the microscope. Although I cannot be certain that this rock is genetically related to the kodurite series of the Vizagapatam district, yet the resemblance to the typical kodurite is close enough to justify a provisional inclusion of the Boiráni rock in this series. The only difference is in the composition of the garnet, the Boiráni garnet containing only a small quantity of manganese, whilst the Vizagapatam garnets are highly manganiferous. The Boiráni garnet is cinnamon-coloured in the hand-specimens, and is usually about $\frac{1}{32}$ to $\frac{1}{16}$ inch in diameter. Under the microscope it is yellow in colour. Since much attention has not been given to this garnet, there is little to say about

its characters. The only specific gravity value available is the one calculated from the analysis of the opalized garnet-felspar-rock given on page 257. The value so calculated is 3·76, and is intermediate between the value given by Dana for grossularite, namely 3·55 to 3·66, and that given for andradite, namely 3·8 to 3·9.

At Nautan-Barampur, also in the Ganjám district, there is an occurrence of a rock composed of rhodonite, a manganese-garnet, and blue apatite. The garnet is sherry-coloured and very similar in appearance to that of Boiráni. It has not been analysed, so that it cannot yet be stated if this is another occurrence of grandite.

Aplome.

This is a name given by Haüy to a variety of andradite that had its dodecahedral faces striated parallel to the shorter diagonal of the rhombs instead of, as is customary when striations are present, the longer diagonal. The one analysis given by Dana of a specimen from Altenau happens to be manganiferous, containing 3·02% of MnO; but it is apparently not known if these striations necessarily indicate the presence of manganese; for the aplome of the other localities does not seem to have been analysed. The only record of aplome in India is contained in E. Balfour's catalogue of the Rev. Mr. Mazzy's Madura collection of minerals[1], and in J. H. Nelson's more detailed account of the same[2]. The latter mentions the occurrence of aplome near Solavandán, about 12 miles west of Madura, and near Melavalavu, about 20 miles N.-E. of Madura. This record is to be considered doubtful in the absence of any account of how the mineral was identified.

Calderite.

Occurrence.

In 1850 H. Piddington published a paper in the *Journal of the Asiatic Society of Bengal*, Vol. XIX, pp. 145 to 148, entitled 'On Calderite, an undescribed Siliceo-Iron-and-Manganese-Rock, from the district of Burdwan'. From this paper it appears that he obtained specimens of the rock to which he has given this name from 'Kut-Kumsandy 12 miles N.-W. of Házáribágh,' as well as from the Burdwan district; But the particular part of the latter district from which the specimens

[1] Catal., Govt. Central Mus., Madras, p. 3, (1855).
[2] 'The Madura Country', pp. 14, 27, (1868).

were obtained is not specified. He distinctly states that calderite is a rock composed of two minerals. One of these is quartz, the other being a mineral which, to judge from his descriptions and the analysis he gives, must be a garnet. The hardness of the rock that he analysed is given as 7 to 8 and the specific gravity as 3·65, the garnet being evidently the principal mineral and the quartz only present in comparatively small amount. As the fresh fracture of the rock is described as being exactly like black rosin, whilst splinters are described as being 'sometimes highly translucent like dark brown rosin', it is evident that the garnet must have been one of the very dark brown varieties approaching melanite in appearance. In fact, in a subsequent paper [3], in which he describes a series of specimens of calderite, ranging from quartz containing only a small amount of the garnet up to rocks probably entirely composed of garnet, he particularly says, regarding the rock composed mostly of quartz, that the iron and manganese mineral in the rock is 'seen only in small and minute rounded specks like Melanite garnets'.

In the former paper he gives the following analysis of the rock composed mostly of the garnet:—

Silex	46·35
Alumina	0·35
Lime	1·00
Arsenic	0·20
Perox. Iron	30·18
Protox. Manganese	21·00
	99·08
Loss, partly fluorine, of which there are traces	0·92
	100·00

Composition.

Mallet, in discussing this analysis in his Mineralogy of India, p. 90, notes that the excess of silica above that which would be present in a garnet may be due to the quartz that Piddington says was disseminated through the specimen. He also remarks on the fact that the ratio of peroxides to protoxides is quite wrong for a garnet, and on this account 'and the inaccuracy of one or two other analyses by the same author' regards the above analysis as very doubtful. This is an unnecessary

[1] *Jour. As. Soc. Beng.*, XX, pp. 207 to 210, (1852).

assumption. It is probable that in carrying out the analysis Piddington weighed the iron as Fe_2O_3, and the manganese as Mn_3O_4, and that he assumed the iron to be present in the rock as Fe_2O_3 and the manganese as MnO. In fact he probably omitted to determine the amount of available oxygen in the rock. Had he done this he might have found that a portion of the iron was present in the protoxide form, giving the correct ratio of peroxide to protoxide for a garnet. On the supposition that the analysis is substantially correct, only lacking the determination of the available oxygen, it can be re-arranged mineralogically as follows :—

Garnet :—		
MnO	21·00	
CaO	1·00	
FeO	7·56	
Al_2O_3	0·35	
Fe_2O_3	21·78	
SiO_2	25·28	
	76·97	76·97
Quartz		21·07
Oxygen		0·84
Arsenic		0·20
Loss		0·92
		100·00

The 0·84% of oxygen left over according to the foregoing interpretation was not, of course, determined to be present, and is to be regarded as another part of the undetermined constituents. If this interpretation be the correct one, then it is evident that we have here a garnet corresponding to the formula $3MnO.Fe_2O_3.3SiO_2$. None of the six type garnets possesses this formula, so that it seems possible that a seventh is to be added to the six garnets at present recognized. It will be desirable to use the term *calderite* to describe this garnet rather than the whole rock. Mallet has in fact already used this term as the name of a mineral rather than of the rock in which it occurs. But he has unfortunately used it, in his Mineralogy, page 89, for a garnet that contains only traces of manganese, as well as for the highly manganiferous garnet to which it properly belongs. He says : ' In the metamorphic rocks of the Hazáribágh district irregular beds of massive garnet, some-

times of considerable thickness, are met with '. He refers to this massive garnet as that which Piddington called calderite, and gives an analysis by Tween showing only traces of manganous oxide, but showing on the other hand a large percentage of lime. The analysis shows that the garnet analysed approaches sufficiently near to the theoretical composition of andradite to be called by that name. The name calderite is therefore wrongly applied to this garnet; unfortunately this mistake has been repeated in Dana's System of Mineralogy. I have been able to find in the collection of the Geological Survey of India one specimen of calderite labelled 'A. S. B.'. This means that it formed part of the collection of the Asiatic Society of Bengal; and it is presumably one of the specimens that were examined and described by Piddington. The rock is composed almost entirely of garnet and in fact could be described as massive garnet. In the hand-specimen it is a dark resin-brown as looked at from a little distance. When examined closely, however, it is seen to be of a rich orange-brown wherever a crack renders a portion of it transparent. There is some red in the colour of this mineral, so that it looks very like some specimens of spandite in appearance. I tested it for manganese, and found that it reacts distinctly but not strongly for this element, so that the Piddington's analysis was either made on a piece of different composition, or Mallet's supposition as to its inaccuracy is correct. In places the specimen contains a dark green pyroxene. It is obvious that it will need a careful analytical examination of this garnet before it can be considered proved that it is a manganese-iron-garnet conforming to the formula $3MnO.Fe_2O_3.3SiO_2$.

During 1906 a specimen was received in the Geological Survey Office of a rock from Sirsia, $5\frac{1}{2}$ miles N.-E. of Kharagdiha, in the northern part of the Házáribágh district, the sender being Mr. J. W. Boilard. The rock seems to be similar to that mentioned by Mallet [1] as being found in the bed of the Patru nadi, N.-E. of Gulgo, in the north part of the same district. He describes it as a mixture of garnet and coccolite containing traces of galena and copper. He refers to the garnet when it occurs in the massive form as calderite. Mr. Boilard's specimen consists essentially of a mixture of a rich brown garnet and a bright green pyroxene, with galena present in parts of the rock, sometimes in abundance and sometimes only sparingly. Under the microscope the garnet is seen to be brownish pink in colour and the pyroxene very

[1] *Rec. Geol. Surv. Ind.*, VII, p. 34, (1874).

pale bluish. On testing it is found that both minerals react for manganese, the garnet very strongly, and the pyroxene distinctly, but not strongly. It seems probable that both this and the case mentioned by Mallet are occurrences of calderite. From its colour the pyroxene may be suspected to be related to the manganese-pyroxenes of the blanfordite type. The galena has been introduced subsequent to the formation of the rock by the process of metasomatic replacement. Along cracks the garnet is usually finely crystalline, showing faces of the rhomb-dodecahedron.

CHAPTER VII.

MINERALOGY—*continued.*

Silicates (*contd.*)—Epidotes, Micas, etc.

Piedmontite—Ilvaite—Carpholite—Manganese-micas—Manganchlorite?—Manganophyllite—Alurgite—Ottrelite.

Piedmontite.

The characters of this mineral as given by Dana are summarized below :—

Characters.

It belongs to the monoclinic system, crystallizing in prismatic forms isomorphous with epidote, of which it is the manganese variety. Also found massive. Cleavage *c* perfect ; *a* less so. Fracture uneven. H. = 6·5. G. = 3·4 to 3·52. Lustre vitreous. Colour reddish brown and reddish black. Streak reddish. The most striking character of this mineral is its beautiful pleochroism as seen in thin sections under the microscope. The pleochroism scheme varies in specimens from different localities, but is generally—

a = yellow to orange.
b = amethyst or violet to rose.
c = rose to carmine.

In composition the mineral is a basic orthosilicate conforming to the formula $Ca_2(AlOH)(Al,Mn,Fe)_2(SiO_4)_3$ or $H_2O.4CaO.3(Al,Fe,Mn)_2O_3.6SiO_2$. The amount of manganese oxide, Mn_2O_3, in the published analyses varies from 4·52 to 15·00, corresponding to 3·5 to 10·5% of manganese.

This mineral cannot be considered a common one ; it is found in the crystalline schists of Japan, in the altered pre-Cambrian rhyolites of Maryland and Pennsylvania in the United States of America, and in Piedmont, Brittany, and England.

Mangan-epidote.

Ordinary epidote may be manganiferous, but this *mangan-epidote* is to be distinguished from true piedmontite by the fact that it is, like epidote, optically negative, whilst piedmontite is optically positive. Such mangan-epidote is found at Jakobsberg in Sweden, and it is the analysis of this mineral that gives the lower limit for Mn_2O_3 given above.

Thulite and withamite.

Other epidotes that have pleochroism schemes similar to those of piedmontite are *thulite* and *withamite*. Thulite is a variety of the orthorhombic epidote, zoisite, and does not contain manganese. In fact no orthorhombic manganese-epidote seems to be known. Withamite is a variety of ordinary epidote containing a very small percentage of manganese. It is found at Glencoe in Scotland and an analysis by Heddle showed only 0·14% of MnO. The pleochroism schemes of thulite and withamite are shown below :—

Thulite.	Withamite.
a = light rose.	a = lemon-yellow.
b = deep rose.	b = light rose.
c = yellow.	c = strong rose.

It will be seen from this that the pleochroism tints of these two minerals are similar, except that the colours for the a and c axes of withamite, which corresponds in pleochroism to piedmontite, are interchanged in thulite.

Distinction between the different manganiferous epidotes.

It is obvious from what has been written above that it must be a matter of considerable difficulty to settle, merely from the examination of thin sections under the microscope, whether the mineral is one of the epidotes, withamite or thulite, containing little or no manganese, or whether it is one of the more manganiferous ones, piedmontite or mangan-epidote. But a test for manganese, made on a small carefully picked chip of the mineral will be sufficient to settle this point. For if a decided reaction for manganese be obtained the mineral cannot be thulite or withamite, but must be either piedmontite or mangan-epidote. It is more likely to be piedmontite, because this is much commoner than mangan-epidote, but as noticed above the only way to determine this point is to determine the sign of the mineral, a positive sign characterizing piedmontite and a negative mangan-epidote.

Occurrence in India.

The investigation of the Indian manganese-ore deposits has led to the discovery of this mineral at several localities in the Archæan schists of the areas where the rocks of the gondite series are found. The following is a list of localities :—

Central Provinces—
Nágpur district:—Ghogara, Junapáni, Junawáni, Mahárkund, Mohugáon, Páli, Rájkota.

Central India—
Jhábua State:—Kájlidongri.

Bombay—
Nárukot State:—Jothvád.

Although this mineral is found only in areas in which rocks of the gondite series occur, it does not usually occur actually in the rocks of this series, but rather in the crystalline limestones of the same neighbourhood. Thus in the Nágpur district the mineral occurs in association with crystalline limestones at all the localities except Mahárkund, where the mineral was found in loose blocks of epidote-rock. At Kájlidongri and Jothvád, on the other hand, some of the occurrences of piedmontite are in rocks intimately associated with the rocks of the gondite series. Below I give a list of the rocks in which piedmontite occurs at each of the known localities :—

Ghogara :—As granules and nodules, both in gneiss, composed of quartz, felspars, and some sphene, and in crystalline limestone : some specimens show a passage from gneiss into limestone, by the chemical replacement and alteration of felspars with the production of calcite (see Plate 10, figs. 3 and 4).

Junapáni, Junawáni, and Rájkota.—As granules, in crystalline limestone containing quartz and mica (phlogopite?).

Mahárkund :—As fine-grained patches in epidote-rock, the rock, which was found in loose blocks, probably occurring *in situ* in association with crystalline limestones or pyroxenic gneisses.

Mohugáon :—As granules, in crystalline limestone containing also a small amount of quartz and sphene.

Páli :—As granules and small patches, in crystalline limestone usually containing quartz, and in fine-grained granulitic gneiss containing quartz, plagioclase, orthoclase, mica, apatite, sphene, and sometimes spessartite and a colourless amphibole (see Plate 10, fig. 2). In the latter rock there is often present a certain proportion of calcite of secondary origin forming at the expense of the felspars.

Kájlidongri :—The mineral occurs here under two distinct circumstances. (1) One occurrence is in a rock composed of spessartite, quartz, plagioclase, and orthoclase (?), the rock being a part of the ore-body and in process of conversion into manganese-ore. (2) The other is that mentioned on page 680 and illustrated in fig. 1 of Plate 18, where the mineral has been developed on the schistosity planes of some sericitoid phyllites, in the part of a sharp fold into which these rocks have been thrown where the pressure was obviously most intense, the other portions of the rock being free from this mineral.

Jothvád:—At this place several specimens of rocks containing this mineral were collected, and are as follows:—

(1) Crystalline limestone containing spessartite, rhodonite, and piedmontite.

(2) Spessartite-calcite-quartz-rock containing apatite, wollastonite, piedmontite, and a lavender-coloured mineral not yet identified. This rock might be called a calciphyre.

(3) Banded rock of which one layer, 1-inch thick, consists of apatite-spessartite-piedmontite-rock, the latter being the most important constituent.

(4) As black crystals of piedmontite associated with white quartz, lining a vein-like cavity traversing the remainder of the rock, which consists of bands of apatite-spessartite-piedmontite-rock and of spessartite-quartz-rock, containing apatite, piedmontite, and pyroxene.

(5) As rose-pink patches in granite at the place where it has absorbed portions of the rocks of the manganiferous series.

I have examined slides of all these rocks under the microscope and find that they exhibit the colours characteristic of manganiferous epidotes. Considering their associations it is improbable that any of them are withamite or thulite; for they must all be manganiferous, except perhaps the Mahárkund occurrence. I have not yet been able to examine them carefully enough to determine their sign and thus settle if any of them are to be called mangan-epidote rather than piedmontite. In most cases it will probably be a matter of extreme difficulty, because only chance sections of the mineral obtained in microscope slides will be available. In a few cases at Páli the pleochroism tints are pale, and it then seems possible that the mineral is only a variety of common epidote containing a small quantity of manganese. Provisionally, however, I propose to group all these occurrences under piedmontite.

Characters of Indian piedmontite.

In one case only have I observed definite crystal faces. This is in the Jothvád rock, No. 4, where the mineral lines what seems to be the two sides of a veinlet. The crystals are up to $\frac{1}{8}$ inch long and one especially good example shows faces that are, as far as can be determined without actual measurement, the following:—*a* (100), *c* (001), and *r* (101), forming a prism parallel to the *b* axis, terminated at one end by faces that may correspond to the prism *m*(110) and one of the

pyramids. The mineral, when not crystalline, usually occurs as disseminated grains, especially in the crystalline limestones and the gneisses associated therewith, and as nodules, also in the crystalline limestones. In these limestones the piedmontite nodules are usually associated with nodules of manganese-ore, and sometimes a nodule of manganese-ore is bordered with a thin rim of piedmontite, as in Plate 14. The origin of these limestones and gneisses is discussed on pages 298—302. In the phyllite of Kájlidongri the mineral occurs in the form of small prisms.

In colour the mineral varies from black, as in the crystals of Jothvád, to dark reddish-black and deep crimson, the latter colour being best seen in the piedmontite nodules found at Ghogara. In these nodules, which are often as much as 3 inches long, the piedmontite is sometimes in parallel fibres, so that the mineral has then some resemblance to crimson silk. In the first of the Kájlidongri rocks the mineral may be described as being of a pansy-purple colour.

The colour under the microscope is very striking, consisting of various shades of yellow, orange, red, pink, amethyst, magenta, carmine, and even blood-red, the latter being an exceptional colour. Some of these colours are, of course, not true axis colours, the colour seen in any random section under the microscope being usually compounded of all three axis colours in varying proportions. In a few cases I have worked out the pleochroism scheme. These are given below:—

	a	b	c
Ghogara	Canary yellow	Salmon to pale pink	Amethyst to carmine or rose.
Mohugáon	Patchy yellow and orange.	Burnt sienna to clove-brown.	Amethyst to carmine.
Jothvád No. 1	Deep orange-red	Very deep red with amethyst tinge.	Deep amethystine or crimson lake.
Jothvád No. 2	Orange to orange-scarlet.	Magenta or deep amethystine.	Brownish lilac to reddish chestnut.
Kájlidongri No. 1	Orange to brownish orange.	Violet-rose with a brownish tinge.	Magenta to rose.

The above determinations should be regarded as provisional only and liable to modification when the Indian piedmontites are more carefully examined. The other characters noticeable under the microscope are the high index of refraction, and the very high double refraction, although this is difficult to observe, except in extremely thin sections, owing to the strong colouration of the mineral. Further the mineral is often twinned.

Ilvaite.

This is a black orthorhombic mineral of specific gravity about 4 and hardness 5·5 to 6. It is a sub-silicate of the formula $CaFe''_2Fe'''Si_2O_9$, in which a portion of the ferrous iron is usually replaced by manganese. The analyses given by Dana show 0·74 to 8·66% of MnO. Ilvaite has not yet been identified in association with the manganese-ore deposits of India. But it is mentioned in E. Balfour's catalogue of the Rev. Mr. Muzzy's collection from the Madura district [1] that it has been found in this district; he says 'YENITE, is abundant, composing a cliff in a small mountain, some three or four miles in length, *Madura*.' Whilst J. H. Nelson [2], in giving an account of Muzzy's collection, records the occurrence of crystallized, massive, and granular yenite, and a variety of lievrite near Puda-kudi, about 22 miles N.-W. of Madura. Yenite and lievrite are old names of this mineral, now no longer used. The record of the occurrence of the mineral given above is to be considered doubtful.

Carpholite.

This mineral is a hydrous sub-silicate corresponding to the formula $2H_2O.MnO.Al_2O_3.2SiO_2$, in which a portion of the alumina may be replaced by ferric oxide and a portion of the manganese protoxide by small quantities of lime and magnesia. It is usually found in radiate and stellate tufts of some shade of yellow, typically a straw-yellow. It is a rare mineral, originally found in the Schlackenwald, Bohemia, but since discovered at a few other localities.

This mineral has not yet been definitely identified in India. But at Kájlidongri a bright yellow mineral is found in little veinlets, 2 to 4 inches thick, that traverse the ore in cross-cut 7 (see Plate 19). These veinlets consist of quartz, albite-felspar, and this yellow mineral, with a certain proportion of crimson mica in places. The rock has become largely manganized, perhaps by replacement effected by manganese-bearing solutions. The yellow mineral looks like yellow asbestos and seems to be soft; but this is probably because, on testing such a finely fibrous mineral, the fibres are easily broken. In appearance the mineral resembles carpholite more closely than any other mineral in the collection of the Geological Survey of India. I made a qualitative analysis of it and found that it contained silica, iron, aluminium, manganese,

[1] Catal., Govt. Central Mus., Madras, p. 9, (1855).
[2] 'The Madura Country', pp. 15, 27, (1868).

calcium, and a trace of magnesium. The amount of manganese does not seem to be very large, whilst the Al_2O_3 is probably less than the Fe_2O_3 in amount, and the amount of CaO is considerable. Water, however, seemed to be absent. But for the latter fact the mineral might have been regarded as a variety of carpholite in which a large portion of the MnO was replaced by CaO and a large portion of the Al_2O_3 by Fe_2O_3.

I have mentioned this mineral in this place because of its outward resemblance to carpholite, but recognize that when it is analysed it will probably be found to be a different mineral, perhaps even one of the yellow manganiferous amphiboles.

In E. Balfour's catalogue of the Rev. Mr. Muzzy's collection of minerals and rocks [1] there is a record of the occurrence of this mineral in the Madura district; whilst J. H. Nelson [2] in giving a more detailed account of Muzzy's collection, mentions the occurrence of 'karpholite' near Puda-kudi, about 22 miles N.-W. of Madura. This record is to be considered doubtful.

Manganese-micas.

Very little work seems to have been done on micas characterized by the presence of a quantity of manganese sufficient to produce any appreciable effect on the physical characters of the mineral. Nearly all the micas may occasionally contain a small amount of MnO, but this rarely affects the colour or other properties of the mica to an appreciable extent. There are, however, three micas containing manganese, to which separate names have been given. These are *manganophyllite*, *caswellite*, and *alurgite*. In this place we will also consider the mineral known as *manganchlorite*, as it is difficult to tell from altered varieties of manganophyllite. *Manganophyllite* is a manganiferous variety of biotite found at Pajsberg, Längban, and probably Jakobsberg, in Sweden. Its formula may be represented as follows :—

$$(H,K)_2(Mg,Mn)_2(Al,Fe)_2(SiO_4)_3.$$

that of ordinary biotite being—

$$(H,K)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3.$$

The analyses given by Dana show 5·41 to 21·40% MnO. In colour the mineral is bronze to copper-red, with a pale red streak. In thin scales rose-red. The pleochroism is :—

$\parallel c$ (b, c) = colourless or pale yellowish red.
$\perp c$ (a) = deep reddish brown.

[1] Catal. Govt. Central Mus., Madras, p. 3, (1855).
[2] 'The Madura Country', pp. 15, 27, (1868).

Some varieties show a maximum absorption for rays with vibrations at right angles to *c*, unlike other micas ; but in those containing most manganese the absorption is normal, the pleochroism then being :—

a = red-brown.
b and c = dark brown.

Certain intermediate kinds show no pleochroism. The optic axial angle of this mica is not given, but is probably small or *nil* ; for biotite is usually practically uniaxial, although the optic axial angle may occasionally be as high as 50°.

Caswellite is the name given to an altered mica of a light copper-red colour and a bronze-like lustre resembling clintonite (seybertite). The structure is micaceous, the laminæ being inelastic. G.=3·54. The mineral is not pleochroic and on analysis was found to be a silicate, chiefly of manganese and calcium, with smaller amounts of aluminium, iron, and magnesium. The one analysis published shows 15·95% of Mn_2O_3. It occurs with rhodonite, polyadelphite, and biotite, from which it is believed to have been derived, at the Trotter Mine, Franklin Furnace, New Jersey, United States of America.[1]

Alurgite :—This is a name given to a mica found at the manganese mines at St. Marcel, Piedmont. It has been investigated in some detail by S. L. Penfield,[2] who finds that it is to be regarded as a distinct species of the formula $HR_2(AlOH)Al(SiO_3)_4$ with R=MgOH, K. It is most closely related to lepidolite. The quantity of manganese in the mineral is small, namely 0·87% Mn_2O_3 and 0·18% MnO in the specimen analysed by Penfield. The mineral is monoclinic with the usual basal cleavage, whilst the laminæ are flexible. H=3. G=2·83 to 2·85. In colour it is a deep brownish copper-red, whilst 'cleavage pieces have something of the colour of clear chips of almandine garnet'. The streak is rose-red to pale pink. The pleochroism is not very marked owing to the fact that the absorption is nearly the same in all directions. The pleochroism is :—

a and c = red with a purplish cast.
b = brownish red.

The optic axial angle, 2E = 56° to 57°. Owing to twinning, however, the mineral is sometimes found to give a uniaxial figure.

Manganchlorite is a manganiferous variety of the chlorite known as clinochlore, the formula of this mineral being $H_8Mg_5Al_2Si_3O_{18}$: in manganchlorite there is 32·3% of MnO replacing a part of the MgO.

1 Dana, Appendix I, p. 14.
2 *Amer. Jour. Sci.*, XLVI, pp. 288 to 291, (1893).

The mineral is found at the Harstig mine near Pajsberg, Sweden, in association with manganophyllite, which it resembles, but from which it is distinguished by a lighter reddish colour. The double refraction and pleochroism are weak, whilst the mineral is distinctly biaxial. Certain characters point to the possibility of this chlorite being triclinic.

Indian Manganese-micas and Chlorites.

Associated with the Indian manganese-ore deposits of the gondite series there is a considerable variety of micaceous minerals; these are in most cases true micas, but occasionally may be either chlorites or altered micas. Although micas are comparatively common in some of these deposits, it is usually in the deposits of somewhat exceptional character, such as those where micaceous schists have been developed. The mineral is very rare in the true gonditic rocks. From these micaceous minerals we can first separate the variety that may be either manganchlorite or an altered mica. This mineral is found only in the Central Provinces, usually intimately associated with the manganese-ores; it has not yet been found in the rocks of the gondite series associated with the ores. The localities for this mineral are the following :—

Manganchlorite.

Bálághát district :—Ramrama.
Bhandára district :—Kosumbah, Sukli.
Chhindwára district :—Kachi Dhána, Sitapár.

The mineral occurs in small books in the midst of the manganese-ore and almost always seems to be suffering alteration with the production of manganese-ore, probably by replacement. In colour it is bronze- to copper-coloured, and gives a bronze-coloured streak.

A flake of the Kachi Dhána mineral was found under the microscope to give a biaxial interference figures, to be rich deep brown in colour, and to contain star-like inclusions, probably indicating the development of some secondary manganese-ore. The flakes were flexible but not elastic. A flake, examined to see that it was free from these inclusions, was found on fusion with the usual fluxes to give a distinct reaction for manganese. At Sitapár the mineral occurs in a rock containing four manganese-ores and an arsenate, as noticed on page 786. Some of the plates of the micaceous mineral from this locality are a greasy brown in appearance, whilst others are of a bronzy, almost copper, brown. The optic axial angle was found to be exactly the same as that of a flake of muscovite of which the optic axial angle was known to be 70°. A

basal section showed the following pleochroism, assuming the two axes lying in this plane to be b and c :—

c = greenish brown to pale brownish green or sage-green,
b = red-brown to raw sienna.

I have called this mineral manganchlorite ? because the flakes or laminæ are not elastic. The pleochroism shows that this cannot be the same as the Swedish manganchlorite and it may be that it is really an altered mica ; but in this case it could not be regarded as manganophyllite, which it resembles in its colour, because of its high optic axial angle. If an altered mica, it cannot be caswellite, both on account of its pleochroism and because it looks very different to a specimen of caswellite in the Geological Survey collection. Hence if a mica it must be a new variety. Provisionally, therefore, I shall call it *manganchlorite* ?, and will so refer to it whenever I have occasion to mention this mineral in the descriptive part of this Memoir. This will thus serve to distinguish the mineral from all the other micaceous minerals found in the manganese-ore deposits ; for these are all true micas, as is shown by the elasticity of their flakes.

Brown Micas (Manganophyllite ?).

Micas showing some tint of rich brown, bronze, or deep orange, are fairly often found in the micaceous schists, of which a list is given on page 333, associated with the rocks of the gondite series. The following is a list of the places at which such micas have been found :—

Bombay :—Jothvád.
Central India :—Kájlidongri.
Central Provinces—
Bhandára district :—Sítapathúr.
Nágpur district :—Ghogara, Junawáni, Kácharwahi, Páli, Rámdongri, Sátak.

Some of these micas are uniaxial and some of them biaxial, sometimes strongly so. It is possible that some of them may be manganophyllite, but it is almost certain that there are two or more species amongst them. I will notice three of the occurrences only.

Jothvád :—Many of the rocks I collected at this place contain brown micas. Although some of these are uniaxial and some biaxial, there does not seem to be a sufficient difference between their tints to enable one to tell without obtaining an interference figure which micas are uniaxial and which biaxial. The pleochroism is :—

a = orange, pinkish yellow, and orange-pink,
b and c = deep orange, reddish orange, and red-brown.

Sitapathúr :—The dark brown mica associated with the crimson mica mentioned on page 198 is uniaxial and has the following pleochroism :—

a = pale straw,
b and c = rich orange-brown.

In thick sections there is seen to be a difference between the b and c axis colours. They may then be described as :—

b = orange-red,
c = mahogany-brown.

Flakes of this mineral give a distinct reaction for manganese on fusion with the usual reagents.

Junawáni :—The mica, which occurs along the cleavage planes of the manganhedenbergite noticed on page 131, is bronze to copper-coloured and under the microscope shows the following pleochroism :—

a = mahogany-red to brownish pink,
b and c = warm light brown, often with an orange tinge.

The absorption is c slightly greater than b. The optic axial angle is large.

Alurgite(?).

Under this name we can group provisionally the various crimson and pink micas found in association with various of the manganese-ore deposits of India. In comparison with the micas of some tinge of brown or bronze the rose and crimson micas are rare. I have found them at four localities only :—

1. Kájlidongri, Jhábua State, Central India.
2. Sítapathúr, Bhandára district, Central Provinces.
3. Ghogara, Nágpur district, Central Provinces.
4. Kácharwáhi, Nágpur district, Central Provinces.

These micas are found in the following rocks :—

1. *Kájlidongri* :—Here the mica occurs as a deep crimson mineral in complex rocks associated with the winchite-bearing rocks, these rocks containing winchite, blanfordite, braunite, apatite, felspar, quartz, calcite. The rock is often much altered and the micas consequently seem to have to a large extent lost their elasticity and under the microscope are seen to be altered and to be made up of alternating laminæ showing different schemes of pleochroism. The one showing rose and amethystine tints is the predominant one : it is not known whether the laminæ showing orange tints are original or the result of the alteration of certain laminæ of the crimson mineral. That it is more probably original is shown by the fact that a similar mica as far as pleochroism goes is also found at Jothvád, in this case apparently in a fresh

condition. Owing to the interlamination of these two micas the determination of their pleochroism schemes is a matter of difficulty.

2. The *Sítapathúr* mica occurs in a rock composed of this and a bronze mica (page 197) with quartz, the whole rock as far as could be judged from the outcrop forming one wall of the manganese-ore deposit at this place.

3. At *Ghogara* the mica occurs in some thin cracks $\frac{1}{64}$ to $\frac{1}{32}$ inch wide traversing the nodules of manganese-ore that are found in the crystalline limestone at this place. The colour of the mica is light crimson.

4. At *Kácharwáhi* there are numerous layers of micaceous schist interbanded with the layers of manganese-ores and other manganiferous rocks forming the manganese-ore deposit. These micas vary in tint from specimen to specimen, some being pink, some brown and others of intermediate colour. When they are examined it may be that some of them will be found to belong to alurgite.

The pleochroism schemes of these micas and their optic axial angles as determined by means an eye-piece micrometer and comparison with a flake of muscovite of known angle, are shown in the following table :—

TABLE 18.

Optical properties of pink micas.

Locality.	Colour in hand-specimen.	Optic axial angle.	Pleochroism.		
			a	b	c
1. Kájlidongri.	Crimson	..	Crimson layers : Amethystine.	Brownish pink to light rose.	Deep rose.
			Orange layers : Greenish yellow.	Pale green.	Orange-red to deep orange.
2. Sitapathúr	Rose red	47°—60°	Pinkish lilac	Light pinkish orange.	Rose.
3. Ghogara	Rose-red or light crimson.	59°—65°	Lilac	Yellowish pink	Light rose to lilac-rose.
4. Kácharwáhi.	..	..	..	..	..
5. Jothvád .	..	..	Pink	Pale green	Orange.
6. St. Marcel Piedmont (Alurgite).	Deep brownish copper red.	56°—57°	Red with a purplish cast.	Brownish red	Red with a purplish cast.

On comparing the pleochroism of these Indian rose and crimson micas with that of the alurgite from St. Marcel in Piedmont, it will be seen that although the pleochroism schemes are somewhat different, the colours corresponding to each elasticity axis have a general resemblance to one another. Thus the brownish tint in the red of the b axis of the typical alurgite corresponds to the yellowish, brownish, and orange, tints in the otherwise pink colour corresponding to the b axis of the Indian micas. It will also be noticed that the optic axial angles of the Indian micas bear a general resemblance to those of the St. Marcel mineral, especially in the case of the mica from Sítapathúr. Hence these Indian micas can be provisionally regarded as alurgite, until they have been subjected to the test of analysis.

The mineral from Jothvád of which the pleochroism is given is not one of the crimson micas, but is a rich brown. Its pleochroism, however, corresponds closely, except in the a axis, with that of the orange laminæ in the crimson mica of Kájlidongri.

Ottrelite.

This mineral belongs to the clintonite group of the mica division of the hydrous silicates. Its formula is doubtfully given as $H_2(Fe, Mn)Al_2Si_2O_9$, and the analyses given by Dana show 0·93 to 8·96 % of MnO. For the purposes of microscopic work, however, chloritoid and its varieties are also grouped under ottrelite in Rosenbusch–Idding's 'Microscopical Physiography', 4th edition, p. 289, (1905), and the formula $H_2(Fe,Mg,Mn)Al_2SiO_7$ given for the whole group of minerals. All ottrelites contain manganese and only some clintonites, but as it is often possible to distinguish the minerals only by chemical analysis, Rosenbusch-Idding's practice will be adopted here, with the understanding that ottrelite proper contains manganese. It is characteristically found in phyllites and schists that have been formed by the metamorphism of argillaceous sediments, though it is not a common mineral. I am not aware if any of my colleagues have met with this mineral in their studies of Indian rocks. I have myself found that it is not uncommon in the phyllites and mica-schists forming parts of the Chilpi Ghát series in the Central Provinces, and in their more metamorphosed equivalents, the mica-schists, usually mapped as a part of the metamorphic and crystalline complex. These Chilpis, as is explained elsewhere in this Memoir (page 282), are the equivalents of the Dhárwár of Southern India and the Arávallis of Rájputána; hence future

microscopic research on these latter rocks may lead to the discovery of ottrelite in them also. Accepting the definition according to which the mineral always contains manganese it is evident that the sediments from which the phyllite or schist was formed must have contained this element in appreciable proportion.

The localities at which I have found ottrelite are (1) in mica-schists at the boundary of the villages of Sitasáongi and Chikhla in the Bhandára district, at the point mentioned on page 763, (2) in the phyllites and phyllitic schists lying on the west of the Bálághát-ore body, and (3) in the mica-schists overlying the manganese-ore body at Ukua, in the Bálághát district. It is not all the micaceous phyllites and schists at these localities, however, that contain ottrelite, and it is often very difficult to detect any external difference between two rocks one of which contains ottrelite, whilst the other does not. The characteristic rock found both at Sitasáongi and Bálághát contains quartz, muscovite, tourmaline, rutile, and a black ore, probably ilmenite, in addition to the ottrelite. The curious intergrowth of the rutile and ilmenite is noticed on page 313. When visible in the hand-specimen the ottrelite is seen to be of a darkish green colour. The evidence on which I base the determination of this mineral as ottrelite is (1) the fact that it gives a distinct reaction for manganese when it is possible to isolate a piece for testing, and (2) its appearance under the microscope. In the first place in sections showing the basal cleavages the extinctions are often oblique, the value of this angle rising to as much as 18°. In the second place the birefringence is very low, whilst thirdly the pleochroism is that characteristic of ottrelite. The pleochroism schemes made out from slides of the Sitasáongi and the Bálághát rocks, respectively, are shown below :—

Sitasáongi.	Bálághát.
a = olive-green,	a = olive-green.
b = plum-blue to indigo-blue.	b = indigo-blue.
c = pale yellowish green.	c = pale yellowish.

The scheme given for Sitasáongi is exactly that given in Rosenbusch-Iddings, 4th edition, p. 292. Occasionally twinning is seen in sections across the cleavage.

CHAPTER VIII.

MINERALOGY—*continued.*

Titano-silicates, Niobates, Phosphates, and Tungstates.

Greenovite—Tscheffkinite—Columbite—Manganapatite—Triplite—A manganesian phosphate—Wolfram.

Greenovite.

Greenovite is a red variety of sphene or calcium titanosilicate ($CaTiSiO_5$) found at St. Marcel in Piedmont. It owes its colour to a small percentage of manganese.

In one spot on the small hill at Jothvád in Nárukot State, a small vein or apophysis from the surrounding granite traverses the manganiferous banded rocks forming the main mass of the hill. This vein is composed of pink felspar (microcline and oligoclase with a little orthoclase), with a certain amount of interstitial quartz, and a large number of prisms and granules of dark-coloured minerals. The granules and stumpy prisms consist of a manganese-garnet and blanfordite, respectively. Besides these two minerals, however, there is a manganiferous variety of sphene. It occurs in small dark brown prisms up to nearly $\frac{1}{4}$ inch long, which, when detached and placed on the stage of the microscope, are seen to be transparent and pleochroic in yellow-green and a pale warm brown, the two colours being of about equal strength. The crystals are elongated, simulating a prism, in which the apparently prismatic faces are really drawn-out pyramid faces, *n* (111), the crystal being several times as long as broad. At the ends they are terminated by faces that are probably *c* (001), *a* (100) and *m* (110) these faces being all of small size compared with the *n* faces. The crystals are in fact very similar to that shown in figure 6, page 713 of Dana's System of Mineralogy, 6th edition, with the exception that the *x* face is wanting and the *n* faces are very much elongated in the direction of the vertical axis. The mean value of the angle *nn'* as measured on the reflecting goniometer over two edges of a crystal was found to be 43° 30′, whilst the value given by Dana is 43° 49′; the images were not very bright or distinct. In thin sections under the microscope the mineral is found to be biaxial, and to show the very high refractive index and

double refraction characteristic of sphene. The colour of the mineral is not, however, that of ordinary sphene, but more intense. Cross sections of the mineral showing diamond shapes, of acute angles measuring 30° to 50°, give the following scheme of pleochroism :—

Axis of greater elasticity = yellow-green to greenish yellow,
Axis of lesser elasticity = orange-red and brown-red to almost rose.

If the mineral be sphene then these axes should be the b and the c axes respectively. The tints for these two axes in deep-coloured varieties of sphene are :—

b = yellow, often greenish,
c = red with a tinge of yellow,

i.e., practically the same as given above. A test for manganese distinctly showed this element to be present, though only in small amount. Mr. Blyth, of the Geological Survey, carefully tested the mineral and proved the presence of titanium. The mineral is therefore a slightly manganesian variety of sphene, *i.e.*, *greenovite*, the manganesian nature of the mineral accounting for its striking pleochroism.

Tscheffkinite.

This is a mineral that was first found in India by Leschenault in 1817 or 1818. It was first analysed by Langier in 1825 and was for some time not given a definite name, but was called the 'minéral de Coromandel' by Beudant in his 'Traité de Minéralogie'.[1] The name 'tschewkinite' was first given to the mineral in 1842 by G. Rose [2] when the author investigated a specimen from the second locality for this mineral, namely the Ilmen Mountains in the Ural. The Indian mineral was later more accurately analysed by Damour.[3] For a long time the locality of this mineral in India was vaguely given as the coast of Coromandel. Mr. F. R. Mallet, however, in 1892,[4] in a paper entitled 'Note on the locality of Indian Tscheffkinite', showed that the exact locality is probably Kanjamalai hill, 5 miles W.-S.-W. of Salem, Madras Presidency.

Tscheffkinite is a mineral of very complex composition, and, owing to the fact that the mineral analysed seems to be in all cases an alteration product, the true formula of the mineral is not known. It is classed

1 Vol. II, p. 652, (1832) [Dana].
2 'Reise nach den Ural.....', II, (1842) [Dana].
3 *Bull. Soc. Geol. de France*, 2nd Ser., XIX, p. 550, (1862).
4 *Rec. Geol. Surv. Ind.*, XXV, pp. 123-127, (1892).

by Dana amongst the titanosilicates. The composition of the Indian mineral as analysed by Damour is shown below :—

SiO_2	19·03
TiO_2	20·86
Ce_2O_3	38·38
Al_2O_3	7·72
FeO	7·96
MnO	0·38
MgO	0·27
CaO	4·40
H_2O and volatile matter	1·30
	100·30

Langier's analysis showed 1·20% of oxide of manganese, probably Mn_3O_4. The specimens from the Urals show 0·75 to 0·83% MnO.

According to Des Cloiseaux,[1] the Indian

'matière n'est pas parfaitement homogène, car j'ai reconnu au microscope qu'elle se compose d'une masse brune sans aucune action sur la lumière polarisée, dans laquelle sont enchassés de très-petits grains incolores fortement biréfringents'.

The characters of the Indian mineral are as follows :—H. = 5·5—6. G. = 4·26. Lustre vitreous, inclining to resinous; colour brownish black, translucent.

'Tschewkenite' is also recorded as having been found by the Rev. C. F. Muzzy[2] near Dindigul, 'forming a constituent part of porphyritic granite'. But the mineral has never been found since, and it is doubtful if the identification was correct.

Columbite.

Columbite and tantalite are two related minerals, the former being theoretically a niobate or columbate of iron and manganese and the latter a tantalate of the same two metals, the theoretical formulæ being $(Fe,Mn)Nb_2O_6$ and $(Fe,Mn)Ta_2O_6$, respectively. In Nature minerals corresponding to the foregoing formulæ are very rarely found, there being every gradation from columbite to tantalite by the replacement of niobium by tantalum, so that the more general formula is $(Fe,Mn)(Nb,Ta)_2O_6$. With an increase in the amount of tantalum and a corresponding decrease in the amount of niobium in the mineral there is a continuous increase in the specific gravity, so that by determining this constant it is possible to decide whether to call a particular specimen

[1] 'Manuel de Mineralogie', I, p. 554, (1862).

[2] Catal. Govt. Central Museum, Madras; 'Madura, its rocks and minerals', p. 9, (1855);
J. H. Nelson. 'The Madura Country', p. 15, (1868).

columbite or tantalite. When the amount of manganese present is very high the mineral is known as mangano-columbite, or mangano-tantalite, according to its composition. The amount of manganese protoxide, MnO, shown in the analyses quoted by Dana varies from 0·81 to 13·88%. No analyses have yet been made of Indian specimens. The specific gravity ranges from 5·3 to 7·3. H.=6. The colour is usually iron-black with a sub-metallic to sub-resinous lustre.

This mineral has been found at four localities in India, two of them in the Monghyr and Házáribágh district, Bengal, one in the Nellore district, and one in Mysore State. Probably in all cases, the mineral occurs in mica-bearing pegmatites. It was first found at the Dattu Mines, Pananoa Hill, near Nawadih, East Indian Railway, Monghyr district, by Mr. H. H. French,[1] the specimens sent being identified by Dr. T. H. Holland. The occurrence of the mineral was then examined by Dr. Holland who found that it occurs 'in lumps imbedded in the quartz of a very coarse grained pegmatite dyke, intruded into a mica schist, which is crowded with tourmaline crystals.'[2]

The mineral was next found by the late Mr. A. M. Gow Smith in the Government forest of Koderma in the Házáribágh district, Bengal.[3] The specimens from this locality were found to have a considerably higher specific gravity than those from Nawadih, namely 6·19, as against 5·54.

The third find was by Dr. T. L. Walker in the mica-bearing pegmatite of Chaganam, Nellore district, Madras, the specific gravity of the mineral being 5·75.[4]

The mineral has also been found by B. Jayaram who writes [5]—

'About 100 yards from the tank bund and 3½ furlongs north of Masti occurs a vein of pegmatite traversing the hornblende granitoid gneiss. It is singularly rich in a dark mineral probably columbite.....This black mineral has been observed in a few places altering into biotite'.

Masti is in the Bangalore district, Mysore.

Judging from the specific gravities given above the mineral from each of the three first localities contains more Nb_2O_5 than Ta_2O_5, and is therefore to be called columbite rather than tantalite. The value of columbite and tantalite depends rather on the percentage of tantalum than on that of the niobium present. Judging from the specific gravity

1 *Rec. Geol. Surv. Ind.*, XXVII, p. 1 at end of volume, (1894).
2 *Rec. Geol. Surv. Ind.*, XXVIII, p. 10, (1895).
3 *Rec. Geol. Surv. Ind.*, XXX, p. 129, (1897).
4 General Report of the Geological Survey of India for 1898–99, p. 9; *ibid.*, 1899–1900, p. 9.
5 *Rec. Mysore Geol. Dept.*, III, p. 182, (1900–01).

of the Koderma specimens the mineral from this locality must contain a considerable amount of Ta_2O_5.

The Reverend Mr. Muzzy reports the find in the Madura district of a mineral resembling ferro-tantalite, this being an old name for tantalite.[1] In Nelson's 'Madura Manual', p. 16, (1868), the ferro-tantalite is stated to occur near Palani, doubtless the same place as Palni, about 69 miles N.-W. of Madura, in porphyritic granite, this information being based on the notes and specimens of Muzzy.

Manganapatite.

Apatite is a mineral belonging to the hexagonal system and having a composition corresponding to one of the two formulæ $3Ca_3P_2O_8.CaCl_2$ and $3Ca_3P_2O_8.CaF_2$, according as it contains chlorine or fluorine, the two varieties being known by the names chlor-apatite and fluor-apatite, respectively. Sometimes a portion of the calcium is replaced by manganese and the mineral is then known as *manganapatite*. The analyses given in Dana show 1·35 to 10·59% of MnO in the examples grouped as manganapatite. These manganapatites are all fluor-apatites. In colour they tend to be dark green or bluish green. One example, namely that from Branchville, Connecticut, containing 10·59% of MnO, has a higher specific gravity than is usual for apatite, namely 3·39, the ordinary value being 3·17—3·23. This is doubtless due to the high percentage of manganese protoxide, and probably a careful investigation of the specific gravities of manganapatites would point to an increase of specific gravity with increasing percentage of MnO.

On page 1063 reference will be found to a veinlet of apatite in spandite-rock at the Kodur mine, Vizagapatam district. This apatite, of which I have several specimens, is of a lavender colour, breaks with a conchoidal fracture, and has then a glassy appearance. Chemical examination shows that the mineral is fluor-apatite, small pieces of which give a distinct reaction for manganese. As the mineral is very much cracked and these cracks usually contain thin black films of manganese oxide, some difficulty was experienced in picking out pure pieces for this test. The mineral is cavernous and then sometimes shows signs of the faces of the hexagonal prism. In these cavities the apatite is always coated with a thin skin of a white enamel-like substance having a nacreous lustre. A small piece of the apatite was found to have a specific gravity of 3·22. Under the microscope the mineral often shows numerous

[1] E. Balfour, Catal. Govt. Cent. Museum, Madras; 'Madura, its rocks and minerals', p. iv, (1855).

opaque white bands parallel to the vertical axis c, so that at first sight the mineral looks like a felspar with lamellar twinning. The apatite with these bands shows a satiny lustre on the fracture surfaces. The mineral is also traversed by fairly numerous cleavages parallel to the basal plane.

On page 1073 is mentioned the find at Devâda, also in the Vizagapatam district, of a large quantity of green apatite in corroded hexagonal prisms up to five inches in diameter. Some of the crystals show pyramidal terminations. A carefully selected chip of the mineral gives a weak reaction of manganese. The apatite is a fluor-apatite and therefore can be designated at length as *mangan-fluor-apatite*. On a fresh fracture it shows a beautiful deep sea-green colour. Under the microscope in a small chip it exhibits a rich pleochroism, namely ω = rich green and ϵ = blue-green. Absorption is $\epsilon > \omega$. The specific gravity as determined in the Geological Survey Laboratory on a large number of carefully picked small chips is 3·16.

From the place in which this mineral is said to have been found, it is probable that it came from a very coarsely crystallized variety of kodurite, in fact from a sort of kodurite-pegmatite. The Kodur mineral, which occurs as a veinlet in a spandite-rock, is to be regarded as the product of segregation from the mass of manganiferous rock during cooling. As therefore this apatite is probably an original mineral, and was moreover probably one of the first minerals to crystallize out, it is not surprising that it should have taken up a small quantity of manganese.

Probably most of the apatite contained in the rocks of this series is more or less manganiferous, though in most cases the apatite is in too small grains for this supposition to be tested except at the expense of a considerable amount of time and trouble.

Triplite.

Triplite is a monoclinic orthophosphate of the formula $(RF)RPO_4$ or $R_3P_2O_8.RF_2$, with R = Fe and Mn, and also Ca and Mg in subordinate amount. It is a heavy dark brown to black mineral of specific gravity 3·4—3·8, and hardness 4 to 5·5; and is found at several localities in different parts of the world. The amount of MnO present varies in the analyses given by Dana from 14·86 to 54·14%.

This mineral has been found in India in considerable masses in pegmatite near the mica mine, 2 miles S.-E. of the village of Singar in the

Gáya district, Bengal. Uraninite (pitchblende), uranium-ochre, and torbernite, are found at the same place as the triplite.[1] The mineral was first found by Kishen Singh of the Geological Survey and identified by Dr. T. H. Holland.

The Indian specimens show various shades of dark brownish black, but are occasionally lighter brown. They have horny lustre. One mass is eleven inches long and weighs forty-one lbs., this including a very small amount of attached quartz.

A Manganesian Phosphate.

At Branchville in Connecticut, U. S. A., is a vein of albitic granite containing a most remarkable series of manganesian phosphates :—dickinsonite, eosphorite, fairfieldite, fillowite, hureaulite, lithiophilite, natrophilite, reddingite, triphylite,[2] triplite, and triploidite. Considering the abundance of phosphorus in the form of apatite in the manganese-silicate-rocks of India, one would expect a careful search to lead sooner or later to the discovery of a similar series of manganiferous phosphates. Apatite, and consequently phosphorus, is most abundant in the rocks of the kodurite series of Vizagapatam ; but up to the present, with the exception of manganapatite, no manganesian phosphates have been found in these rocks. In the rocks of the gondite series at Jothvád in Nárukot, Bombay, apatite is also very abundant ; but it is unaccompanied by any other phosphates, as far as has been at present ascertained, although there are minerals at this deposit that have not been at present identified and of which no mention is made in this Memoir. In the rocks of the gondite series in Jhábua and the Central Provinces on the other hand, apatite is usually much scarcer, although sometimes found in abundance. At one locality, namely Chárgáon in the Nágpur district, Central Provinces, a different phosphate is found. It occurs in a very beautiful rock composed of orange spessartite trapezohedra up to $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter, set in a martrix of rose-pink rhodonite in plates sometimes an inch in diameter. With the rhodonite is mixed a varying proportion of barytes and an oil-green mineral. In some places the latter mineral is present in some abundance. It occurs in irregular patches sometimes an inch in diameter. It just scratches apatite and so can be considered to have a hardness of 5 - 5·5. Its specific gravity as determined by means of Sonstadt's solution is

[1] T. H. Holland, *Mem. Geol. Surv. Ind.*, XXXIV, pp. 32, 51, (1902).

[2] See a series of papers by O. J. Brush and E. S. Dana in the *Amer. Jour. Sci.*, Vols. 16-18, 39, years 1878-1879, and 1890.

3·404 to 3·409, or, say, 3·40 to 3·41. It fuses rather easily to a dark-brown mass, and is found by qualitative analysis to be a phosphate of manganese, magnesium, and sodium, with a little calcium, and possibly a little iron. Water is doubtfully present. The mineral is uniaxial and slightly dichroic.

The uniaxial character of the mineral was determined by means of an interference figure obtained in a chance section. If true it is a most important character, because none of the manganesian phosphates are uniaxial except manganapatite, which is quite different to this mineral in most respects. Hence there seems to be no alternative to regarding this mineral as a new species. In case the determination of the uniaxial character of the mineral be at fault it is as well to see what minerals this phosphate is otherwise most closely related to. In specific gravity and hardness it agrees with natrophilite, an orthorhombic mineral of the formula $NaMnPO_4$. But it differs from the latter in containing magnesium in addition to the other constituents, and in being green in colour instead of wine-yellow, the colour given for natrophilite. It agrees with dickinsonite in colour, and fairly closely in specific gravity. It is, however, harder, and is practically free from iron, containing magnesium instead. These are the only phosphates to which the mineral seems to have any resemblance. Hence even if the two determination of the uniaxial character of the mineral be at fault it must still be regarded as a new mineral. I do not, however, propose to name it until its characters and chemical composition have been more fully ascertained.

Wolfram.

Characters.

Wolfram or wolframite is a heavy dark brownish to black mineral of monoclinic crystallization. H.=5 to 5·5. G.=7·2 to 7·5. The streak is usually some shade of dark reddish brown to black. Perhaps one of the most characteristic features of this mineral is the perfect cleavage parallel to the plane *b*, so that the mineral looks as if it were laminated. In composition it is a tungstate of iron and manganese. When the latter is present to the exclusion of iron the mineral is called hübnerite.

Occurrence in India.

In India wolfram has been found in the Házáribágh district, Bengal,[1] and in several places in Burma. In the latter area placer deposits of tinstone are to be found in many of the streams and rivers draining down from

[1] *Rec. Geol. Surv. Ind.*, XXI, p. 21 (at end of volume), (1888).

the range of granite hills and mountains that separates Lower Burma from Siam, and stretches north from the Pakchan river bounding the Mergui district on the south, through the whole Tenasserim division, to a point at least as far north as Karenni in the Southern Shán States. Many of these placer deposits have been stated at different times to contain wolfram. A complete account of these occurrences cannot be given here, but will be given later in the article on tungsten in the 'Mineral Resources of India', when this is published. It is sufficient to say here that wolfram has been recorded from Karenni, and the districts of Amherst, Mergui, and Tavoy, but never *in situ*. This present year (1907), however, Mr. J. J. A. Page of the Geological Survey has found wolfram *in situ* in the parent rock. The locality is in a 15-foot wide reef on North Hill near Máliwun; of two specimens brought from here by Mr. Page, one shows the wolfram in a quartz matrix without any other minerals, and the other consists of quartz containing wolfram, cassiterite, and a little copper pyrites, the wolfram being in allotriomorphic crystals up to 1 inch long. The other locality is 6 miles south of Inner Bokpyin in the same district, the rock in which the wolfram occurs being that known locally as 'kra', which is a decomposed tourmaline-granite containing tinstone. In this case Mr. Page detected the mineral only after panning the rock for tinstone, the wolfram not being visible in the hand-specimen.

A specimen recently received from Mr. Kellerschon was found, on being tested by Mr. G. G. Narke of Nágpur in the Geological Survey laboratory, to be wolfram. One piece is three inches long. In December 1907, I was able to visit the locality of the find—Agargáon in the Nágpur district—; the mineral occurs in quartz veins interbedded with mica-schists, and with associated tourmaline-schist.[1]

[1] *Rec. Geol. Surv. Ind.*, XXXVI, part 4, (1908).

CHAPTER IX.

MINERALOGY—*continued.*

Associated Non-Manganiferous minerals.

Graphite—Chalcopyrite—Pyrite—Pyrrhotite—Halite—Rose quartz—Amethyst—Chalcedony and chert—Opal—Iron-ores—Hematite—Limonite—Magnetite—Martite—Gibbsite—Microcline—Sapphirine—Lithomarge and kaolin—Arsenates—Distinction of arsenates, apatite, and barytes—Barytes.

On pages 35, and 323—5 are lists of the minerals associated with the manganese-ore deposits of India. A large number are not of sufficient interest to require any notice beyond that necessary in connection with the rocks in which they occur. A few, however, of which a list is given on page 35, are of more interest, usually on account of being found in crystals or masses of size sufficient to be examined without the use of the microscope. About these I propose to give here a few notes.

Graphite.

Graphite has been found at only two localities in association with manganese-bearing rocks in India. Both these occurrences are in the Vizagapatam district. One was in one of the manganese-pyroxenites found at Chintelavalsa, the graphite being present in scales up to $\frac{3}{4}$ inch across, associated with the quartz, in a rock composed of spandite, quartz, green pyroxene, rhodonite, and graphite, with also small quantities of biotite, apatite, and sphene. The other occurrence was as a loose block in the valley to the south of Táduru on the way to the Táduru occurrence of manganese-pyroxenite. The rock was a soft decomposed rock found under the microscope to be composed of garnet (spandite), apatite, and manganese-ore, with abundance of the graphite, very conspicuous in the hand-specimen. Graphite was also seen in small quantity in the rock from Táduru noticed below in connection with pyrrhotite. The occurrence of graphite in these manganese-silicate-rocks may be an original feature, or the graphite may have been picked up from the associated rocks of the khondalite series, in which graphite is one of the most characteristic minerals.

Chalcopyrite.

The manganese-silicate-rocks of India and the associated ores are remarkably free from all sulphides. Nevertheless, in one of the gneisses interbanded with the manganese-bearing rocks of Jothvád in Núrukot there is a little chalcopyrite.

the containing rock being an epidote-hornblende-quartz-rock with sphene, apatite, tourmaline, and wollastonite. One occurrence of pyrite has been observed, namely in a hornstone-like chert vein at Kodegáon in the Nágpur district (see page 847). In one case, moreover, I have noticed what may be pyrrhotite. This was in a rock obtained as a loose block below the manganese-pyroxenite outcrop at Táduru in the Vizagapatam district The rock is composed of apatite, spandite, rhodonite, and quartz, with a little graphite and sphene. Under the microscope by reflected light a few scattered granules are to be seen of a opaque metallic bronzy mineral, which may be pyrrhotite.

Pyrite.

Pyrrhotite.

A case has been noticed of a fine white felt of sodium chloride or halite found as a coating on joint planes of the manganese-ore at the Kándri mine in the Nágpur district.[1]

Halite.

A mineral that is not infrequently found in association with manganese-ore deposits in India is the rose-coloured variety of quartz. I have already noted two occurrences in the Chhindwára district, namely at Khairi and Dudhára.[2] Other occurrences of this variety of quartz are as a vein in the decomposed lithomargic rocks at Kodur in the Vizagapatam district (see page 1062), and as large loose hexagonal crystals, of amethystine-rose colour, in the detritus or gravel deposits being sorted over for their loose fragments of manganese-ore at Sandanandapuram in the same district (see page 1075). The quartz associated with a piece of apatite-gondite at Guguldoho in the Nágpur district also exhibited a pale yet decided amethystine tint. Rose or amethystine-rose quartz is doubtless often found under circumstances when there are no strongly manganiferous rocks near by, but all the same one cannot avoid suspecting that the colouration may be connected with the possible presence of manganese in the quartz. Dana in his System of Mineralogy, page 187, puts forward this suggestion, whilst he also mentions that Fuchs found 1 to $1\frac{1}{2}\%$ of titanium in rose quartz from Rabenstein near Bodenmais, and attributed the colour to this constituent.

Rose quartz.

Some three years ago I made an examination of the Khairi rose quartz in conjunction with Mr. T. R. Blyth. We found that the quartz contained a very small quantity of manganese; this could be extracted by boiling the very finely powered mineral with dilute sulphuric acid

[1] *Rec. Geol. Surv. Ind.*, XXXI, p. 237, (1904).
[2] *Rec. Geol. Surv. Ind.*, XXXIII, p. 176, (1906).

and its presence proved by means of the red lead and nitric acid test. No attempt was made to estimate the quantity of manganese present, or to find out the form in which it existed. Under the microscope I found that the quartz contained a large number of minute liquid inclusions similar to those so often found in this mineral. In view of the fact that the manganese could be extracted by boiling with acid and did not require a fusion to release it, it seems probable that the manganese is present in these cavities as a salt in solution and that it only needs sufficiently fine grinding for it to be possible to extract the manganese salts in solution. Probably if water had been used instead of acid the result would have been just the same.[1]

Amethyst.

The colour of amethyst has also been supposed to be due to manganese (Dana, page 187), and recently the results of some experiments by M. Berthelot[2] have been published showing that this is correct and that the colour can be removed by heating the mineral. It is supposed that the colouring matter is present as a manganic compound and that heating decomposes this into a manganous compound with the liberation of oxygen. It is further stated that the colour can be caused to return by submitting the mineral to the influence of radium. No true amethyst has been found in association with the manganese-ore deposits of India, the nearest approach being the amethystine-rose quartz of Sandanandapuram and the pale amethystine quartz of Guguldoho. In the geodes of the Deccan Trap formation, however, amethyst is not an uncommon mineral; but the colouring is often uneven, the crystals being patchy or zoned. As a locality may be mentioned the railway cuttings on the Shikára Ghâts in the Seoni district, Central Provinces, where I obtained a strongly coloured geode. It does not follow, however, that any more are to be readily found at the same place; for the distribution of geodes and the nature of their mineral contents seem to be most capricious throughout the Deccan Trap formation.

Chalcedony and chert.

In the manganese-silicate-rocks of both the kodurite and gondite series quartz is commonly found as an original mineral. As the result of the chemical changes that have taken place in these rocks, however, there has often

[1] Mr. Blyth has since tried to extract the manganese by using water instead of sulphuric acid: but did not succeed in doing so.

[2] *Comptes Rendus*, CXLIII, pp. 477-488, (1906); abstract in *Jour. Chem. Soc.*, XC, Part II, p. 863, (1906).

been a considerable production of secondary silica; this does not form as quartz, but as either opal or chalcedony; the latter is often impure and coloured by the presence of small amounts of manganese or iron oxides and is then best designated chert. Chert is found in large quantities in the manganese mines of the Vizagapatam district, its colour being as a rule of some shade of brown. Such brown chert is also found in the manganese-ore deposits of the Central Provinces, but not very commonly, and then only in small quantities. In association with the manganese-ore deposits that occur in the crystalline limestones in the Chhindwára and Nágpur districts there is, however, often a considerable quantity of black chert, owing its colour to the presence of manganese oxides, and formed by the replacement of the limestones by silica. Opal is also not infrequently formed in the manganese-ore deposits. Thus it is common in the Vizagapatam mines, as a replacing material for the felspathic portion of kodurite, the product frequently taking the form of manganese-garnet set in a matrix of opal. Good examples of this are seen at Kotakarra (page 1097), Kodur, and at Boiráni in Ganjám (page 1034); see also Plate 8, figures 1 and 2. In the Nágpur district opal is sometimes found filling cracks in the manganese-ores and associated rocks. Good examples are mentioned under Kodegáon (page 847) and Kándri (page 873). Opal is also sometimes found in the Chhindwára deposits.

Opal.

One of the most extraordinary features of the manganese-ore deposits of the gondite series, is the freedom of the manganese-ores from admixture with iron-ores. When it is considered that these deposits are supposed to have been formed either immediately or ultimately by the metamorphism of manganiferous sediments, this rarity of iron-ores is all the more surprising; for it means that when the manganiferous sediments were deposited the mineralized waters from which they may be supposed to have been formed contained large quantities of manganese salts and only a comparatively small quantity of iron salts. It might be argued that these waters really contained considerable amounts of iron salts as well and that the portions that were not deposited with the manganese oxides (for it must be remembered that nearly all the manganese-ores contain a certain amount of iron) were deposited in other parts of the same area where the conditions were slightly different. Were this the case deposits of iron-ores should be found at the same horizon as the manganese-ore deposits, *i.e.*, on the continuation of their strike.

Iron-ores.

Except in the case of the Bálághát deposit, where the band of manganese-ore in tailing out gives place to limonite, this has not been observed. Consequently such occurrences of iron-ores as have been noticed in association with the manganese-ore deposits are of particular interest. The occurrences to be noticed in association with the deposits of the gondite series in the Central Provinces are at Mansar, Mansar Extension, Mándvi Bir and Junapáni (pages 885, 892, 970, 976, respectively).

Hematite.

In all these cases the ore is red hematite, sometimes massive, and sometimes in the form of aggregated small scales of specular hematite. Another occurrence in this series is at Kájlidongri in Jhábua, where there is a vein composed of quartz and hematite traversing the deposit (page 687). The hematite is in micaceous plates up to 2 inches across. But this occurrence, being of vein origin, is not to be regarded as similar to those in the Nágpur district; the latter may be the product of the consolidation and metamorphism of original sediments, although it is perhaps as probable that in at least some cases the hematite is only a secondary introduction. In the manganese mines of the Vizagapatam district no definite deposits of iron-ores are found, but small quantities of yellow ochres are often found mixed with the manganese-ores and are also found in irregular patches in the lithomargic 'country'. In the deposits formed by secondary processes on the outcrops of the Dhárwar rocks, as in Singhbhum, Jabalpur, Sandur, and Mysore, the manganese-ores are commonly associated with iron-ores, usually limonite; in the lateritic deposits also the manganese-ores are almost invariably intimately associated with iron-ores, both hematite and limonite.

Limonite.

Another ore of iron that is sometimes found in association with the manganese-ore deposits of the gondite series is magnetite. Two occurrences of rocks of these series containing magnetite have been found. One of these is at Kodegáon in the Nágpur district where the mineral occurs in a rock composed of magnetite, spessartite, and quartz; the rock is therefore to be called magnetite-gondite. The other is at Kachi Dhána in the Chhindwára district and is a rock composed of magnetite set in a matrix of chalcedony. It is possibly a silicified magnetite-spessartite-rock.[1] Magnetite also occurs as a magnetite-quartz-rock associated with the manganese-ore deposits at

Magnetite.

[1] It has not been proved that these magnetites are non-manganiferous. Considering their association they may be manganmagnetites. But the individual grains of the magnetite are so small and so intimately associated with the other minerals that it would be a matter of extreme difficulty to determine this point.

a few localities, *e.g.*, at Rámdongri in the Nágpur district, on the neck joining hills 5 and 12. Magnetite-quartz-rock is also found at Katangjheri I (Bálághát district) and at Sítapathúr (Bhandára district), the occurrence at the latter locality being in the form of magnetite in quartz resembling vein-quartz. In none of these cases is the magnetite-bearing rock found in any considerable quantity. In some of the Vizagapatam manganese-ore deposits a very magnetic mineral is often found; but in the few cases in which this has been tested it has been found to react slightly for manganese. Hence the mineral has been noticed under the heading of manganmagnetite.

Martite.

At Jámrapáni, Bálághát district, there is a rock associated with the manganese-ore deposit in such a way as to suggest that it is an intrusive. It is composed of quartz, muscovite, and a black mineral, which has the outward shape of magnetite. Some of the crystals when tested give a black streak and are found to be magnetic; these can be regarded as magnetite. Others give a red streak and are less strongly magnetic; these are to be regarded as martite formed by the conversion, more or less complete, of magnetite into hematite. That the change has not been completed is shown by the magnetism that the mineral still retains. Other examples of martite have been found, as for example at Hatora, where there is a rock composed of magnetite, quartz, and some apatite and garnet, in which some of the magnetite seems to have been converted into martite, as evidenced by the streak.

Gibbsite.

As I have already noticed,[1] the oxides of aluminium, iron, and manganese, behave in laterite in a manner exactly parallel with their behaviour in the laboratory. Thus the oxides of aluminium and iron, which are precipitated in the same group in the ordinary qualitative separation, are often very intimately associated with one another in laterites, although they also in many cases separate or segregate from each other. With manganese, however, there seems to be a very strong tendency to segregate from the other oxides with the formation of definite manganese-ores, containing of course a certain amount of oxides of iron and aluminium, more of the iron than of the aluminium. These ores usually take the form of nodules, masses, and veinlets. They are almost always associated with the ferruginous laterites rather than with the aluminous laterites or bauxites. This is of course due to the greater chemical resemblance of manganese to iron than to aluminium. I have, however, noted one case in which an

[1] *Rec. G. S. I.*, XXXIV, p. 168, (1906).

aluminous mineral occurs in close association with manganese-ores.[1] This is at Talevádi in the Belgaum district, where gibbsite, $Al_2O_3.3H_2O$, is found as incrustations and infillings in cracks and cavities in the manganese-ore. The gibbsite must have been formed after the psilomelane, the aluminium oxide having been derived, in all probability, from another mass of the laterite close at hand.

Microcline.

In several of the deposits of the gondite series of the Central Provinces there are intrusive veins, masses, and patches, of felspathic rocks of pegmatitic character, in which the felspar is usually microcline. In one case, namely at Satak II, the microcline was able to develop crystal faces owing to the presence of a vug-like cavity in the rock. The crystals range up to 1·5cm. in diameter and are of a dirty white colour. One of them that is especially well developed shows the basal plane, *c* (001); the prisms, *m* (110), and *M* ($1\bar{1}0$); the brachy-pinacoid, *b* (010); the + hemi-macrodome, *x* (101), and a negative hemi-macrodome.

Sapphirine.

On page 757 I have noted the occurrence in a complex quartzite, forming the 'country' of the Chikhla deposit at one part of its length, of a blue mineral that is to be doubtfully identified with sapphirine.

Lithomarge and kaolin.

As the result of the chemical alteration to which the rocks of the kodurite series in the Vizagapatam district have been subjected large masses of hydrated aluminous silicates have been formed. They are of various colours, white, yellow, pink, and lavender, and, when coloured, probably contain oxides of iron or manganese. The material can be designated by the term *lithomarge*, the name given to the firm, compact and apparently non-crystalline variety of kaolin, $2H_2O.Al_2O_3.2SiO_2$. For it must be noted that although the lithomargic rocks, as seen in mass in the quarries, seem to be very soft and friable so that they give rise to considerable trouble in the quarrying operations, yet often a hand-specimen can be trimmed out of a piece of the material when it is dry. A piece of the white variety was analysed by Mr. J. C. Brown, of the Geological Survey of India, with the following result (1·18% of moisture having first been removed by heating at 100 °C.):—

Combined water	13·08
Silica	49·84
Alumina	36·96
Lime	traces
	99·88

[1] *Rec. G. S. I.*, XXXV, p. 169, (1906).

On grinding the sample for analysis it was found that a little free quartz was present. Consequently the analysis can be recalculated as follows:—

Kaolin	93·42
Quartz	6·40
Surplus alumina	0·06
	99·88

Arsenates.

It is an interesting fact that many of the Indian manganese-ores when analysed are found to contain As_2O_5, though usually in exceedingly small quantities. Thus the highest amount returned in the analyses carried out at the Imperial Institute is, with one exception, 0·022%, and in the analyses made by Messrs. J. & H. S. Pattinson, 0·047%. Nevertheless, it is an important point to determine the form in which this constituent is present in the ore.

The Sitapár arsenate.

At two different localities I have found crystalline arsenates. One occurrence is at the Sitapár deposit in the Chhindwára district, where the arsenate occurs as a pale pinkish white to white mineral mixed up with the manganese-ores. It is usually interstitial with regard to the other minerals present, and is translucent, with a greasy lustre, a rather even fracture, and a white streak. H.=5 in fresh pieces, for the mineral tends to become opaque white and softer. It is brittle and easily crushed and is soluble in dilute acids. Qualitative examination of the mineral shows that it is essentially an arsenate and phosphate of calcium with small quantities of other constituents. As one specimen of the ore contained a piece of this mineral showing three sides of what looked like a hexagonal prism, it is possible that this mineral is isomorphous with apatite. This prismatic crystal shows thin white lines parallel to the basal plane, due perhaps to parting planes. Under the microscope the mineral is allotriomorphic with regard to the manganese-ores, shows a very high refractive index, and polarizes in greys of the first order. In one section two sets of cleavages at right angles were seen. These possibly correspond to basal and prismatic cleavages. Samples 10 and 10A, of which the analyses are given on page 787, of the ores of this deposit contained 0·003 and 0·095 per cent. As_2O_5, respectively, the original sample having been divided into two, one free from visible arsenate and the other containing it.

The Kájlidongri arsenates.

The other place at which arsenates occur is Kájlidongri in the Jhábua State, where two different minerals of this group are found. One of these is in a vein of quartz and barytes, traversing the manganese-ore body at cross-cut 6 (see Plate 19). The arsenate occurs in sparsely distributed rounded crystals up to half an inch long. It is of a sage-green colour and looks exactly like apatite at first sight. That it is not apatite is indicated by its inferior hardness, between 3 and 4, instead of 5. Qualitative examination of the mineral showed it to be an arsenate of calcium and magnesium, with small quantities of other constituents.

The other occurrence of arsenates at this locality is in the N. W. spur workings at the point shown on the plan of this deposit on Plate 19. Here the mineral was found in a rock of which it formed the chief constituent, the other minerals present being quartz, spessartite, and braunite. The relations of this rock to the manganese-ores with which it was associated were obscure and I could not determine if it were a vein rock or a proper member of the gondite series. As seen in a hand-specimen of the rock, the arsenate, on account of its cleavage, suggests a green felspar at first sight, the coarseness of the rock being about that of an ordinary granite. The hardness of the mineral is about 3. Its colour is a pale green. It dissolves easily in dilute hydrochloric acid on heating and gives reactions for water and arsenic in the dry way. It was examined qualitatively by Pandit T. S. Kochak in the Geological Survey Laboratory, and was found to be an arsenate of magnesium with a very little lime and a certain amount of water. Under the microscope the mineral is colourless, shows a high refractive index, and polarizes in colours of the second to fourth orders in sections showing first order colours for quartz. The cleavages are well marked forming two sets crossing like those of calcite. The angle between these cleavages varied from 51° to 65° in those measured. Lamellar twinning is sometimes shown as well as simple twinning. In some cases the section was at right angles to one optic axis, thus showing that the mineral is optically biaxial.

One of these brushes indicated, in a section in which the angle between the two set of cleavage was 60°, that the optic axial plane lies from an acute angle to acute angle of the cleavage rhombs. The mineral is often seen to be undergoing replacement by oxides of manganese. The replacement begins along the cleavage cracks and gradually spreads over the whole crystal. The mineral often contains inclusions of yellow spessartite, which also undergo alteration to manganese-ore. Thus the garnet is idiomorphic with regard to the arsenate ; the latter in its

turn is idiomorphic towards the quartz. Until these arsenates have been analysed quantitatively it will not be possible to say if they correspond to any known species or are new minerals.

Distinction of arsenates, apatite, and barytes.

It is probable that these arsenates are commoner than is suspected. For it must be noticed that under the microscope they often present a great resemblance to both apatite and barytes. All these minerals as seen under the microscope are colourless, with a high index of refraction giving rise to a highly pitted surface. They all show cleavages, and, except in the case of the Kájlidongri arsenate, low polarization colours; and the tendency is for them all to be called apatite if they are seen only under the microscope. Nevertheless, it is comparatively easy to settle which mineral it is that is present, if the quantity be not too small. In the first place if it be very finely powdered and treated with hot dilute hydrochloric or nitric acid, both apatite and arsenates will pass into solution. It is not then sufficient to add ammonium molybdate to the nitric acid solution and assume that the yellow precipitate indicates a phosphate and therefore apatite. The solution should be first treated with a solution of sulphurous acid to reduce any arsenate if present and then a current of sulphuretted hydrogen passed; if a yellow precipitate be formed, it may be assumed that the original rock contained arsenic, probably in the form of arsenate. If no precipitate be formed in this way then the molybdate test may be applied and the yellow precipitate then obtained taken as evidence of the presence of a phosphate, presumably as apatite. If neither an arsenate or apatite be found to be present it will then be as well to make a test for barium by fusing up a portion of the rock with fusion mixture and testing the acidulated extract of this for barium. When the mineral is macroscopically visible it is a much simpler matter to prove the presence of either an arsenate or barytes. The arsenic mirror obtained by heating the mineral with sodium carbonate and potassium cyanide in the closed tube will serve as a good test for the arsenate, whilst the green flame and the blackening of a silver coin will serve as tests to prove the barium and sulphur present in barytes.

Barytes.

I have found barytes in the rocks of the gondite series, apparently as an original constituent, at three localities. For the reason that it may be easily overlooked if one is not on the lookout for it, it is probable that this mineral is much more frequently present in the rocks of this series than I have detected. If its

softness be not tested it is liable to be mistaken for felspar in the hand-specimen, on account of its pearly lustre on cleavage faces. Under the microscope it may be mistaken for apatite if its high refractive index combined with its low double refraction be noticed; whilst if one is hurriedly examining a series of rocks, and does not notice the high index of refraction of the mineral, it may be mistaken for a felspar. The localities at which it has been found as a constituent of rocks of the gondite series are Ghoti, Chárgáon, and Kájlidongri At Kájlidongri this mineral also forms one constituent of a vein traversing the manganese-ore deposit; the other constituents are quartz, the arsenate mentioned on page 219, a black ore, probably braunite, and a small amount of plagioclase felspar. In this vein the barytes individuals may be as much as 2 or 3 inches long. Except for the presence of the manganese-ore and the arsenate, the rock is not unlike the quartz-barytes veins described by Dr. Holland from the Salem district.[1] These veins are considered to be of pegmatitic origin and to have solidified from an injected mobile magma. From the mode of occurrence of the Kájlidongri vein it would be impossible to decide whether it be an ordinary mineral vein or also of pegmatitic origin; but the presence of plagioclase in the rock renders it improbable that it is an ordinary mineral vein. The arsenate, moreover, may be regarded as taking the place of the apatite so often found in pegmatites, and consequently we can regard the Kájlidongri rock as possibly the product of the solidification of an injected magma. The manganese-ore that it contains may easily have been absorbed by the magma from the manganese-ore deposit at the time of its intrusion.

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[1] *Rec. G. S. I.*, XXX, p. 236, (1897).

CHAPTER X.

MINERALOGY—*concluded.*

The Identification of Manganese Minerals.

I propose to give in this section some hints by the use of which the prospector may attempt to identify the manganese minerals that he meets with in association with the manganese-ore deposits of India, considering at the same time certain non-manganiferous minerals that may be mistaken for ores of this element. I shall not consider all the manganese minerals that have been found in India as enumerated on page 34; for some of them, such as wolfram, triplite, and columbite, are not found in association with the manganese-ore deposits and are otherwise rare.

Micaceous structure.

Of the manganese minerals that occur in the manganese-ore deposit we can first separate off those that exhibit a micaceous structure, this being a very noticeable feature. The micaceous minerals can be red, brown, yellow, or green, in colour and will be found described under the headings of manganese-micas (page 195), mangan-chlorite (page 195) and ottrelite (page 199). If the mineral does not show a micaceous structure the first character to be noticed is the colour of the mineral. By far the larger proportion of the minerals found in the manganese deposits will be black, steel-grey or some other shade of dark grey or brownish black, the mineral then usually exhibiting a metallic lustre. The minerals that are not black can be grouped according to their colours as follows :—

Colour.

Minerals not black or grey.

Crimson to crimson-black.

Piedmontite; usually in crystalline limestones; observe pleochroism scheme under the microscope (page 191).

Blanfordite; observe pleochroism scheme under the microscope; sometimes occurs in characteristic crystals that alter to soft chestnut-coloured pseudomorphs; also sometimes greenish (page 125).

Pink.

Rhodonite; not scratched by a knife; does not effervesce with hot hydrochloric acid; rarely greyish-green (page 139).

Rhodochrosite; easily scratched by a knife; effervesces with hot dilute hydrochloric acid; sometimes nearly white and always paler than rhodonite (page 122).

RED, ORANGE-RED, ORANGE-BROWN, ORANGE, AND YELLOW.

Manganese-garnets; characterized either by definite crystalline or by granular form, being nearly always equidimensional in all directions; isotropic character under the microscope (page 161).

Manganese-pyroxenes; in the Vizagapatam district are some red-brown to orange-brown pyroxenes not to be distinguished from garnets except under the microscope, when they are seen to be anisotropic (page 137).

Yellow pyroxenes and amphiboles; there are also yellow manganese-pyroxenes and amphiboles; the former can only be determined microscopically (page 132); the amphibole is usually known by its fibrous or asbestiform character, whilst it may also be brownish or greyish in colour (page 147).

BLUE.

Winchite (page 149).

GREEN.

Phosphates and arsenates; for distinction between these see page 220.

Tests for manganese.

All the foregoing minerals will react for manganese except the arsenates. The best tests for manganese should be known to every prospector for manganese. They are three in number. A very useful one is to make a borax bead on a platinum wire, in the way described in most books on determinative mineralogy, and introduce a little of the powdered mineral into the bead. If the bead is heated in the oxidizing flame, the presence of manganese will be indicated by an amethystine colour, which may become deep red if much iron be also present. If the bead is not too strongly coloured it will become colourless when heated in the reducing flame, owing to the reduction of the manganese to the manganous condition. This test works very well with minerals, such as oxides, that are easily broken up in the bead; but with silicates, such as manganese-garnets, the colour is not obtained quite so readily. The second and the best test is to fuse a small portion of the powdered mineral with a little nitre and fusion mixture or ordinary soda in a platinum crucible, or on a piece of platinum foil bent into the shape of a boat. The presence of manganese in quantity is indicated by a rich green colour; under certain circumstances the colour is greenish blue, usually when the quantity of manganese is not very large. This is a very delicate test and serves to detect very small quantities of manga-

nese, the depth of colour obtained with two minerals, under the same circumstances as to relative quantities of mineral and fluxes, being an indication of the relative amounts of manganese present in the two minerals. The green colour is due to the formation of manganates of sodium and potassium. This is the most useful of the tests and the one that is most generally applicable and gives the result desired in the shortest time. The third test is one that is even more delicate than the fusion test. It is known as Volhard's test and consists in obtaining a nitric acid extract of the mineral under examination and boiling it with lead peroxide. Any manganese present is oxidized with the formation of violet or red permanganic acid, the colour being very similar to that of potassium permanganate. This test is only directly applicable to minerals that dissolve in acids. It is best to dissolve the mineral direct in nitric acid if possible. If the mineral has to be dissolved in hydrochloric acid, it is necessary to take the solution nearly to dryness to remove the hydrochloric acid; for any quantity of this acid prevents the formation of the colour. If the mineral be a silicate it is not as a rule decomposed by acids, so that a fusion is first necessary; and then the green colour will probably be obtained in the course of the fusion rendering the application of Volhard's test unnecessary. Hence this test is only conveniently applied in the case of minerals that are soluble in acids. It has the advantage over the fusion test that it enables one to detect the minutest traces of manganese, such for instance as those to which the colour of rose-quartz may be supposed to be due.

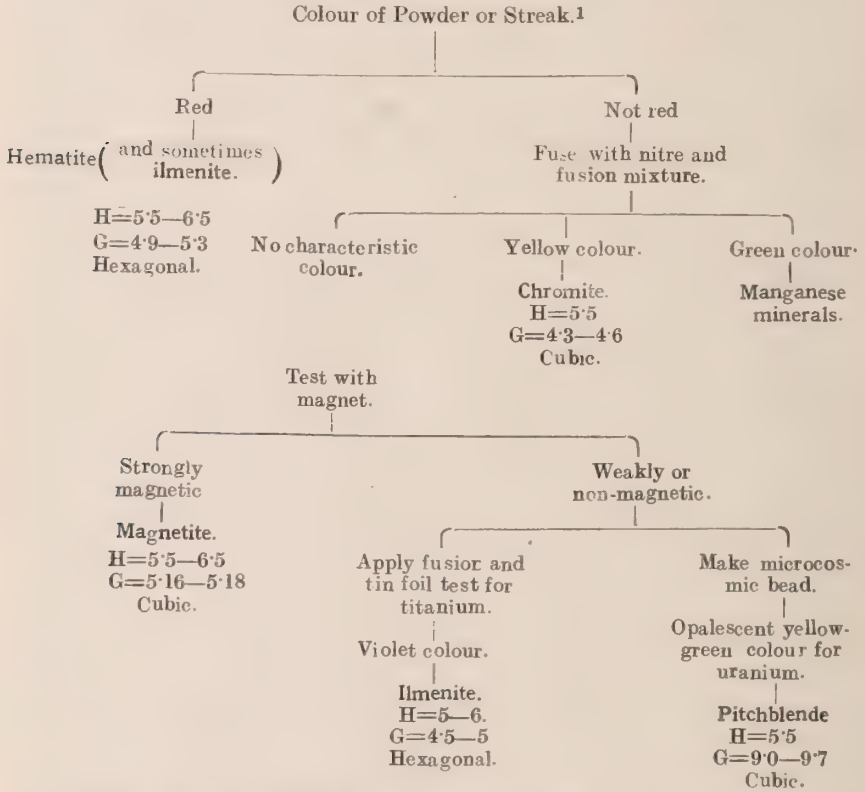
The black and grey minerals.

We can now pass to the dark-coloured minerals, which usually possess some sort of a metallic lustre. The colours shown by these minerals are some shade of black, steel-grey, dark blue-grey, brownish-black, or bronze-black. Owing to the fact that there are several fairly common minerals that may be at first sight confounded with manganese-ores, I will also take them into consideration. Supposing that one has found a piece of a black, or dark grey, or allied-coloured, mineral of considerable weight, it may be either a manganese or iron mineral, or chromite, or pitchblende, as well as various other minerals of great rarity found but rarely or not at all in India. The first test to apply is to powder the mineral, when the colour of the streak becomes evident. The following table shows the way in which the mineral can be either identified as one of the minerals, hematite, magnetite, ilmenite, pitchblende, or chromite, or else separated off as an ore of manganese, the test that decides whether the mineral is a manganese mineral being the fusion test

with the resultant green colour, as explained above. The key is as follows :—

TABLE 19.

A key to the identification of the black and dark grey iron, manganese, and chromium, minerals.



I have given the hardness (H), specific gravity (G), and crystalline system of each mineral. These characters should be determined as far as possible in order to confirm the identification of the mineral from this key. If the mineral reacts for manganese then recourse should be had to the following key, which is for the identification of the black and dark grey metallic manganese minerals found in India, together with a few not yet found in India, the possible existence of which it is necessary to consider.

[1] *Limonite* is sometimes externally black and mammillated so that it resembles the manganese-ore psilomelane. It is, however, distinguished by its yellow-brown streak and absence of reaction for manganese.

TABLE 20.

A key to the identification of the black, dark-grey, and bronze-coloured, manganese-ores.

TABLE 20.

A key to the identification of the black,

I. NOT SCRATCHED BY A PENKNIFE.

	Manganmagnetite	$(Fe,Mn)O.(Fe,Mn)_2O_3$.
2.	Vredenburgite	$3Mn_3O_4.2Fe_2O_3$.
3.	Sitaparite	$9Mn_2O_3.4Fe_2O_3.Mn_2O_2.3CaO$.
4.	Braunite	$3Mn_2O_3.MnSiO_3$ to $4Mn_2O_3.MnSiO_3$.
5.	Franklinite	$(Fe,Zn,Mn)O.(Fe.Mn)_2O_3$.
6.	Jacobsite	$(Mn,Mg)O.(Fe,Mn)_2O_3$.
7.	Polianite	MnO_2.
8.	Psilomelane	$m\,R''_2Mn_2O_5 + n\,R'''_4(MnO_5)_3$; R''=Mn, Ba,$K_2$, H_2, etc.; R''' = Fe, Mn, Al.

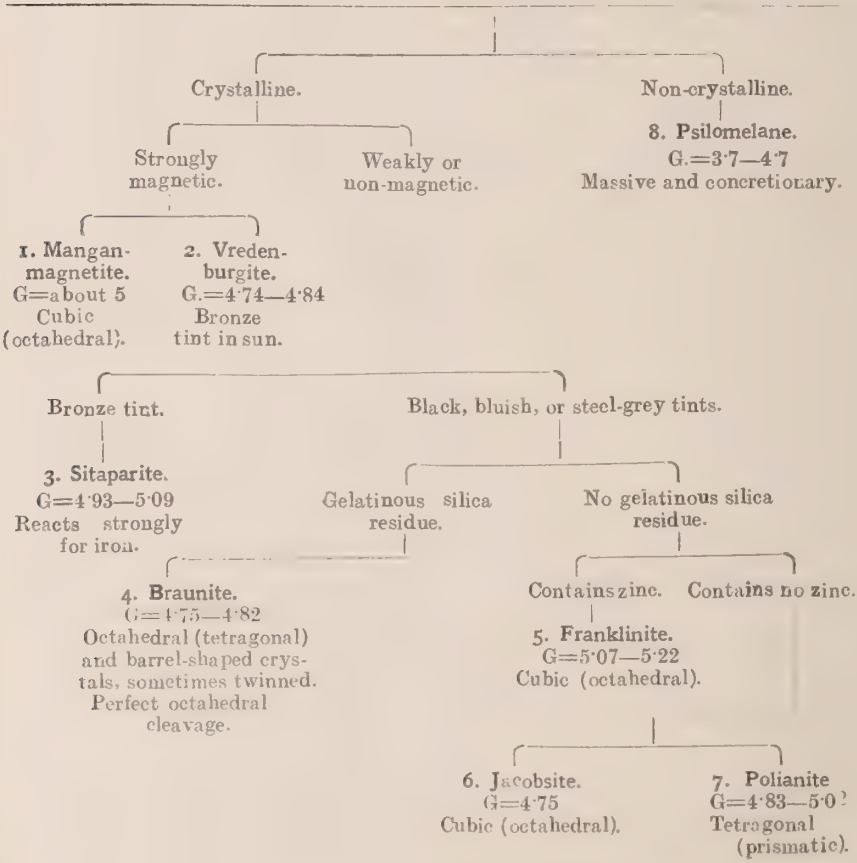
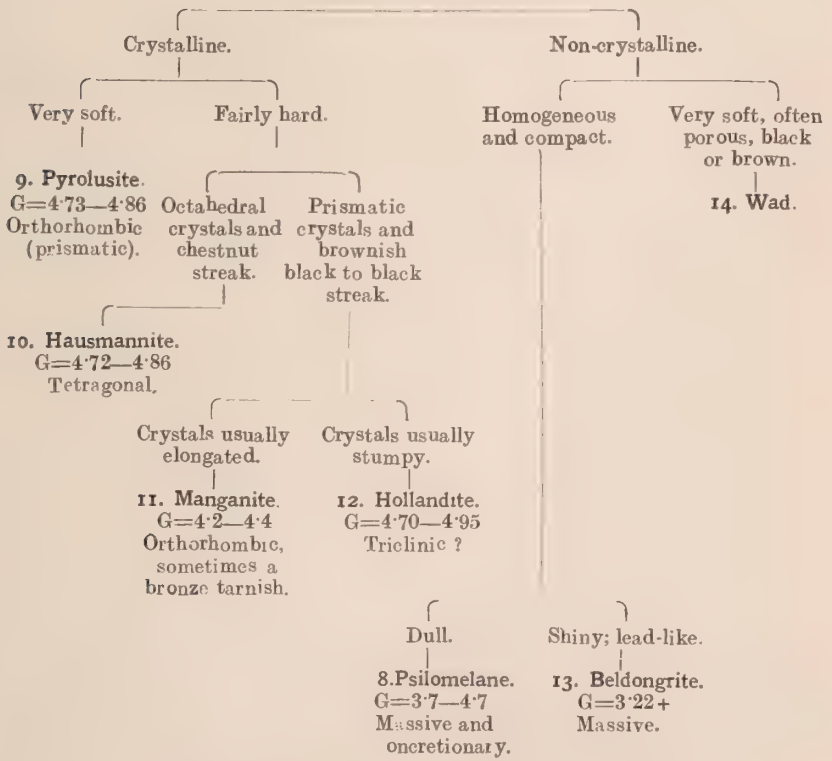


TABLE 20.

dark-grey, and bronze-coloured, manganese-ores.

II. SCRATCHED BY A PENKNIFE.

9. Pyrolusite . . .	. MnO_2.
10. Hausmannite . . .	. Mn_3O_4.
11. Manganite . . .	. $Mn_2O_3.H_2O$.
12. Hollandite . . .	. $m\,R''_2MnO_5 + n\,R'''_4(MnO_5)_3$; R″=Mn,Ba,Ca; R‴=Fe.
8. Psilomelane . . .	. $m\,R''_2MnO_5 + n\,R'''_4(MnO_5)_3$; R=Mn,Ba,$K_2$, H_2, etc., R‴=Fe,Mn,Al.
13. Beldongrite . . .	. $6Mn_2MnO_5.Fe_2O_3.8H_2O$.
14. Wad.	. Indefinite mixture of oxides.



Remarks on the foregoing key.

Before making use of the foregoing table it is usually necessary to obtain pieces of the mineral to be identified free from admixture with other minerals. Usually the ores are sufficiently coarsely crystalline for this to be simply a matter of breaking up the ore into fairly small pieces and carefully selecting those fragments that under a lens are seen to be pure. Sometimes, however, the granules or crystals of the minerals composing an ore are too small to be conveniently separated in this way. If the ore is evidently a composite one it is then necessary to resort to methods of separation that it will not be possible to discuss here. Having obtained a portion of the pure mineral, the first test according to the table is to try and scratch it with a penknife. If the mineral can only be scratched with doubt or not at all, then it is probably one of the minerals in the left-hand portion (I) of the table. It must be noticed that although hollandite is grouped with the minerals that can be scratched it is often not possible to scratch its crystal faces, its true hardness being probably about 6; but if a knife be drawn across the fibrous fracture of the mineral it will be easily scratched. Hence I have placed hollandite with the scratchable minerals. Most psilomelane is not appreciably scratched by a knife; but it is sometimes quite soft and therefore the mineral is placed in both sets of minerals (I and II). The soft varieties are sometimes only to be distinguished from wad by quantitative analysis, when psilomelane will be found to conform to the manganate formula given in the key, whilst wad will be found to be an indefinite mixture of oxides. The test for the presence of silica (SiO_2) is made by dissolving the mineral in hydrochloric acid. A residue of gelatinous silica can be taken to indicate that the mineral is braunite; whilst a residue of a few grains of sand or a very small quantity of silica can be neglected.

It must be borne in mind that the key is not infallible and that in many cases it will be found to be impossible to decide by its aid to which of two minerals a given specimen corresponds. There is then no alternative to making a complete analysis of a carefully picked specimen of the mineral. It is, for example, often a matter of the greatest difficulty to decide whether a particular specimen is pyrolusite or manganite. This is due to the fact that manganite changes into pyrolusite, and that specimens may be obtained in which this change has not been completed, so that the specimen is intermediate in composition between the two minerals. In the same way it is often difficult to decide whether a particular specimen is to be referred to manganite or hollandite, owing to their similar colour,

lustre, and prismatic habit. For although the manganite prisms are characteristically long and thin and those of hollandite stumpy, yet the latter are sometimes fairly long also, and those of manganite sometimes stumpy. A determination of the specific gravity, should, however, settle the point.

White minerals.

The only other minerals to which it is necessary to direct attention are the various white minerals that are found in association with the manganese-ores of the gondite series. Quartz there is no mistaking; but felspar, barytes, and arsenates may easily be confounded with one another, and all regarded as felspar in the field, with the result that a piece of the mineral is not taken away for examination. This also applies to rhodochrosite when it is nearly white. The inferior hardness of the arsenates and the barytes should, however, attract the attention of the prospector. A discussion of the discrimination of those minerals will be found on page 220.

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THE

MANGANESE-ORE DEPOSITS OF INDIA

PART II

GEOLOGY

(MODE OF OCCURRENCE AND ORIGIN)

ABRIDGED CONTENTS OF PART II.

		PAGE
CHAPTER	XI.—General, and the Khondalite Series	235
,,	XII.—Kodurite Series.—Occurrence, Origin, and Chemical Composition	243
,,	XIII.—Kodurite Series.—Alteration	262
,,	XIV.—Manganiferous Rocks of the Dharwar Facies, including the Gondite Series	280
,,	XV.—Gondite Series.—Occurrence and Origin . . .	306
,,	XVI.—Gondite Series.—Mineralogy and Petrology . . .	323
,,	XVII.—Gondite Series.—Chemical Composition and Alteration .	348
,,	XVIII.—Manganese in the Purana, Palaeozoic, and Mesozoic Formations	366
,,	XIX.—Manganese in Laterite	370
,,	XX.—Manganese in the Tertiary and Recent Formations . .	390

THE

MANGANESE-ORE DEPOSITS OF INDIA

PART II

GEOLOGY

(MODE OF OCCURRENCE AND ORIGIN)

CHAPTER XI.

GEOLOGY.

General—Classification of Indian manganese-ore occurrences according to formation—The khondalite series.

General.

The rocks composing the earth's crust can be divided into two main groups :—(1) the fossiliferous ranging in age from recent to Cambrian; and (2) the unfossiliferous, and as far as is known the pre-fossiliferous, or pre-Cambrian rocks. The word 'Archæan' is by many authors taken as synonymous with 'pre-Cambrian'; but it is customary in America to restrict the word 'Archæan' to the older portion of the pre-Cambrian rocks, using the term 'Algonkian' for the unfossiliferous rocks intermediate in age between the Archæan and the Cambrian. In India Dr. Holland proposes to use the term 'Purána', meaning 'old', to designate the series of rocks occupying a position analogous to that of the Algonkian of America.

The Archæan complex.

The Archæan rocks can be supposed to form a continuous shell round the earth and to underlie all the younger rocks. These latter rest in more or less isolated patches on the Archæan shell, areas of which are now

exposed at the surface wherever the denuding agents of Nature have removed the once overlying fossiliferous and Purána rocks. Since the total thickness of the Archæan rocks is probably considerably greater than that of the whole of the post-Archæan rocks, by far the larger portion of the earth's crust must be constituted by these ancient rocks.

The oldest gneisses.

As might be expected, the Archæan group is of extremely complex constitution, and may be supposed to be composed of five main divisions :—

1. The original crust of the globe, by which is meant the portion of it that first crystallized out from the molten condition during the secular cooling of the earth.

2. The sediments formed by the denudation and re-deposition of portions of this crust, the denuding and depositing processes being then, however, vastly different to what we now observe, and probably at least as much of a chemical as of a mechanical nature.

3. The igneous rocks intruded from the still molten interior of the earth into the solid or semi-solid crust composed of 1 and 2. These intrusions were, no doubt, taking place during the whole of the time of formation of 1 and 2.

Sedimentation and igneous intrusion and extrusion must have progressed side by side, accompanied by a constant crumpling up of the rocks thus formed, with a consequent metamorphism of the whole of them into the gneissic condition. All the gneisses thus formed have been so folded together that to separate them one from another is now in all probability everywhere impossible ; especially as these earliest sediments when rendered gneissic must be practically indistinguishable from the rocks from which their material was derived. Consequently all these rocks can be grouped together as the *oldest gneisses*.

The schistose gneisses and the Dhárwárs.

4. Gradually the meteoric conditions must have begun to approach those we now experience, so that true mechanical sediments were formed. The sediments formed were then no longer necessarily of a composition approaching that of the original igneous rocks, but composed of conglomerates, sands, clays, and limestones. There must have been a period of comparative tectonic quiescence during which a vast thickness of these sediments was able to accumulate, accompanied by the extrusion in some areas of contemporaneous basic lava-flows.

Both sediments and lava-flows were then involved in another great series of tectonic disturbances and more or less deeply folded in with the

oldest gneisses. Those portions of the sediments that were carried deep down were converted into schistose gneisses, quartzites both massive and schistose, mica-schists, and crystalline limestones, according to the composition of the sediments : whilst those portions that were less deeply folded in were only metamorphosed to the condition of schistose, cleaved, and often felspathic, conglomerates and grits ; phyllites and slates ; quartzites and sandstone-quartzites ; and fine-grained limestones not markedly crystalline. In India such portions of these sediments as suffered the more severe metamorphism, *i.e.*, that those were rendered thoroughly crystalline, have usually been mapped as part of the crystalline complex, from which they could be separated, in many cases, only by very close field-work : whilst the less metamorphosed portions have been distinguished as the Dhárwár system in Southern India ; and as the Chilpi Ghát series, the Champáners, and the Arávallis in the regions farther north. In this Memoir I propose to extend the name Dhárwár to include the whole of these rocks. The set of earth movements that folded the Dhárwár sediments was probably the last that affected the whole of the earth's crust in this part of the world.

The plutonic intrusives (Bundelkhand granite, charnockite series, etc.).

5. Partly during and partly after the folding of the Dhárwárs great masses of igneous rocks seem to have been intruded into all the previously-formed rocks. Those that were intruded at the time of the folding of the Dhárwárs have necessarily to a certain extent assumed foliated characters, and are usually known as gneissose granites ; whilst those that were intruded subsequently have either no banded structure, or only that due to flow, and can be termed granites, or at the most banded granites. (In other areas where there have been subsequent great earth movements, such as in the Himálayas, such granites have also become gneissose.) These rocks are variously known in the Peninsula of India as the Bundelkhand granite or gneiss, gneissose granite, etc. ; the charnockite series probably belongs to this period.

The Great Eparchæan Unconformity.

In areas, such as the Peninsula of India, where there have been no violent earth movements since the Dhárwár folding, there is of course a great unconformity between all these ancient foliated and schistose rocks and the whole of those that follow. This has been termed the Great Eparchæan Unconformity and the period between this folding and

the appearance of the next series of sediments the 'Great Eparchæan interval'. The term 'Archæan' is conveniently restricted to the rocks lying below this great unconformity, although, as already mentioned, some authors use the term as synonymous with 'pre-Cambrian'.

The Puráua formations.

Between the end of Dhárwár and the beginning of Cambrian times several series of sedimentary rocks, all as far as we know unfossiliferous, have been deposited. Such sediments, originally deposited as sands, clays, limestones, etc., are termed *Algonkian* by the Americans and *Purána* by Dr. Holland.[1] In areas, such as the Indian Peninsula, that have not been involved in any very intense folding movements since Dhárwár times, these sediments have to a large extent escaped any serious alteration of their mineral character, and are now represented by quartzites, sandstones, slates, shales, limestones, conglomerates, etc.: they are known as the Bijáwars, Kadapahs, Vindhyans, etc.

Classification of the pre-Cambrian.

The pre-Cambrian rocks of the Indian Peninsula can therefore be separated into fthe ollowing divisions:—

I. Archæan:—

1. The oldest gneisses (Bengal Gneiss).
2. The schistose gneisses and the Dhárwárs.
3. The plutonic intrusives, such as the Bundelkhand granite and the charnockite series.

II. Purána:—

The Bijáwars, Kadapáhs, Vindhyans, etc.

Derivation of the rocks ranging in age from Cambrian to recent.

From these rocks all the later sediments, frequently containing fossils, and ranging in age from Cambrian to recent, have been formed by denudation and re-deposition, either chemical or mechanical; except that a small portion of the detritus has been derived from various post-Purána intrusions of igneous rocks and extrusions of igneous lava-flows at the surface.

It follows from this that, for the source of any constituent of the fossiliferous rocks, we must refer, either immediately or ultimately, to the Archæan complex, and, within this complex itself, ultimately to the constituents of it that are of igneous origin; except that a certain

[1] *Trans. Min. Geol. Inst. Ind.*, I., p. 48, (1906).

small proportion of the material has been derived from the igneous rocks of post-Archæan age.

The ultimate source of the manganese-ores.

Let us take the case of the element manganese. As has already been mentioned (page 18), the earth's crust contains on the average about 0·10 per cent. of manganese protoxide. Most of this was originally distributed in insignificant proportions in the various ferro-magnesian silicates, such as garnets, amphiboles, pyroxenes, and micas, contained in the Archæan igneous rocks. But igneous rocks have also been found in which highly manganiferous minerals form an important part of the rock : thus in the kodurite series of India manganese-garnets and manganese-pyroxenes are found in abundance ; whilst the albite-pegmatite of Branchville in Connecticut, United States of America, contains numerous highly manganesian phosphates. The operations of Nature at the surface of the earth on the great variety of rocks exposed to her action are nearly always such as to produce, by either mechanical or chemical means, a concentration at particular spots of particular constituents of the rock operated upon. This has led to the concentration at particular spots, in the form of workable deposits of manganese-ore, of a certain proportion of the once widely disseminated element manganese ; and it is now almost impossible to mention a country in which some evidence of the presence of manganese, if not as workable deposits of ore, at least as nodules, impregnations, coatings, or black stains, cannot be found.

Manganese-ore deposits found in rocks of any age.

It follows from what goes before that workable deposits of manganese-ores might be found in rocks of any age whatsoever, all that is required being a favourable combination of circumstances, either mechanical or chemical, enabling the requisite concentration to be effected. Such is found to be the case. Thus the deposits of Brazil and most of those of India lie in the Archæan rocks, those of Arkansas and the Appalachian region of the United States chiefly in the Palæozoic, those of Carniola in the Trias, and those of the Caucasus in the Eocene.

Distribution of the manganese-ores and minerals of India according to formations.

Although most of the workable manganese-ore deposits of India occur in rocks of Archæan age (those in laterite forming the exception), yet manganese-ores and minerals have been recorded from a variety of formations. These are set forth in the following table, the oldest rocks being placed first and the youngest last. It must be noted

that the manganese minerals, especially the oxides and manganates, were not in all cases, or even usually, formed contemporaneously with the rocks in which they occur, and that in many cases they were formed at some unknown period between the time of formation of the rocks in which they occur (this is what is given in the subjoined table) and the present.

TABLE 21.

Classification of Indian occurrences of manganese-ore and manganese minerals according to their geological position.

Group.	Formation or Series.	Localities.
Archæan	Khondalite Series	Ganjám, Vizagapatam.
	Manganese-intrusives (Kodurite Series).	Vizagapatam, Ganjám.
	Dhárwár Facies:—	
	Metamorphic schists and gneisses (Gondite Series).	Bálághát, Bhandára, Chhindwára, Nágpur, and Nárukot.
	Arávali	Banswára, Jhábua, Jhang, Patiála, Ajmere, and Alwar.
	Champáner	Panch Mahals.
	Chilpi Ghát Series	Bálághát.
	Dhárwár (mostly lateritoid)	Belgaum (Bhimgad), Dhárwár, (Tawargatti), Sangli, North Kanara, Jabalpur, Bellary, Sandur Hills, Chitaldrug, Shimoga, Tumkur, Singhbhum and Kálahandi.
	Occurrences of small quantities of manganese-ores and minerals.	Gáya, Házáribágh, Monghyr, Pálánpur, Malvan, Amherst, Karenni, Mergui, Ruby Mines district, Tavoy, Haidarábád, Kashmir, Coimbatore, Madura, Nellore, Salem, Bangalore, and Hassan.
Purána	Kaládgi	Belgaum (Munnikerri), Bijapur (Bágalkot and Kaládgi).
	Bijáwar	Dhár, Indore, Hoshangábád, and Gwalior.
	Vindhyan	Bhopal, Rewah(?), Nimár.
	Krol	Kángra (Dharmsála).
	Jaunsar	Jaunsar.
Dravidian	None; unless the Krol and Jaunsar rocks belong here	

Classification of Indian occurrences of manganese-ore and manganese minerals according to their geological position—contd.

Group.	Formation or Series.	Localities.
Aryan . .	Gondwána { Ironstone shales .	Burdwan.
	Gondwána { Kámthi . .	Nágpur (Siliwára), Wun (Yeotmál).
	Gondwána { Jabalpur . .	Rewah.
	Liassic	Baluchistán.
	Lameta	Dhár, Indore, and Nimár.
	Deccan Trap	Belgaum, Dhárwár, Ratnagiri, Sátára, and Amráoti.
	Laterite[1].	Morbhanj, Belgaum (Talevádi), Bijapur (Ingleswára), Dhárwár (Nagargali), N. Kanara(?), Jabalpur, Goa, Bidar, Chengalpat (Red-Hills), and the Nilgiris.
	Lithomarges on the charnockite series.	The Nilgiris.
	Lateritic gravel . . .	Ganjám (Gudhiári), Nágpur, Bhandára.
	Pre-Tertiary (exact position unknown).	Andamans.
	Nummulitic	Kohát.
	Sabáthu	Afghánistán.
	Fossil-wood group (Pliocene) .	Taung-ngu, Magwe.
	Post-Tertiary	Hantha-wadi.
	Recent (various) . . .	Dhár(Pán Kuán), Nágpur (Pench R.), Allahábád (bones), Ganjám (Rambha and Kálikot), Chitaldrug (black soil), and 24 Parganas.
	Recent (sands) . . .	Haidarábád, Coimbatore, Karnul, Nellore.
	Recent (deep sea) . . .	Maldives.
	Fault-rock of various ages. .	Bundi, Dhár, Indore, Nimár.

[1] Also see lateritoid under Dhárwár.

Khondalite Series.

(Vizagapatam, Ganjám and Orissa.)

The term *khondalite* was given by Dr. T. L. Walker [1] to a series of rocks supposed to be para-schists or metamorphosed sediments; they form, together with garnetiferous biotite gneissose granites and rocks of the charnockite series, the great ellipsoidal outcrop of Archæan crystallines that stretches in a north-easterly direction through Godavári, Vizagapatam, Kálahandi, and Ganjám, to Orissa, and that gives rise to the mountain or hill ranges known as the Eastern Ghâts. The khondalites are composed essentially of garnet, sillimanite, quartz, and graphite; but

[1] *Mem. Geol. Surv. Ind.*, XXXIII, pt. 3, p. 11, (1902).

it seems to have been previously overlooked that everything black in the khondalites is not graphite. In several cases where I have tested little black spots and areas in these rocks, they have turned out to be manganese oxide. One such occurrence near Sandápuram in the Vizagapatam district is noted on page 1115. Near Kálikot in Ganjám little veins and patches of psilomelane are common in an accumulation of boulders of khondalite (see page 1037); whilst among some specimens of khondalite sent as examples of building stone from Orissa, there were two from Khigerimudia, 3 miles south of Jatni near Khurda Road Station, Puri district, showing spots and streaks up to $1\frac{1}{2}$ inches long of soft black manganese oxide giving a brownish black streak.

In none of these cases is the manganese oxide, as such, an original constituent of the rock; it has always been deposited in its present form subsequent to the formation of the rock. According to the analysis shown by Walker[1], khondalite does not contain manganese; but one may suspect that this rock, like most of the ancient crystallines, contains at least a small amount of this element, and that during the action of the weathering processes on those portions of the khondalites lying near the surface the manganese is dissolved out by circulating waters, and re-deposited where the conditions are suitable, this re-deposition being accompanied by a metasomatic replacement of the rock. Some of this manganese oxide, however, has probably been derived from rocks other than those of the khondalite series, such as the manganese-intrusives (kodurite series) of Vizagapatam.

[1] *Mem. Geol. Surv. Ind.*, XXXII, pt. 3, page 9, (1902).

CHAPTER XII.

GEOLOGY—*continued.*

The Kodurite Series of Vizagapatam and Ganjám.

Vizagapatam district—Calcareous gneisses—The kodurite series—Relations to other crystallines—Igneous origin—Nomenclature—Mineralogy—Petrology—Magmatic differentiation—Localities—Occurrence in the Ganjám district—Chemical composition.

Vizagapatam District.

Lying to the east of the Eastern Ghâts noticed above are the coastal plains of Vizagapatam, some 30 to 50 miles wide and not rising to any very great height above sea level. These plains are composed, as far as can be discovered from the scattered outcrops between the patches of alluvium, of a complex of Archæan crystallines of which the two main constituents are the gneissose granites and the khondalites noticed on page 241. These rocks often give rise to small tors and hills, respectively, protruding through the alluvium. Associated with the khondalites, usually at their junction with the gneissose granites, are some very calcareous gneisses regarded by Walker as a part of the khondalite series and, like the khondalites, formed by the metamorphism of sediments. Mineralogically, these gneisses are of very variable composition, but are usually composed of *pyroxene* (macroscopically dark to light green, microscopically light green to colourless; probably diopside), *wollastonite*, *scapolite*, *garnet* (orange-brown macroscopically, and light brown to yellow-brown microscopically), *calcite*, and *sphene*. *Microcline*, *orthoclase*, *plagioclase*, *quartz*, and *apatite*, are less frequent constituents. It is difficult to find a name that can be used so as to include all the varieties of these rocks. Thus the term *scapolite-gneiss* is not generally applicable, because scapolite is frequently absent. The most constant mineral is the pyroxene. But there are so many varieties of *pyroxenic gneisses* that it would be better to avoid this term if possible. Now it so happens that nearly all the minerals in these gneisses contain an abundance of lime, this richness in lime being in fact the most characteristic feature in the chemical composition of these rocks. Hence I propose to refer to them as the *calcareous gneisses* or, for short, the *calc-gneisses*.

The calcareous or calc-gneisses.

Should anyone object to this term as implying that calcite is always present in these rocks, which it is not, the term *lime-gneisses* could be used; it is to be noted, however, that the term *calcareous* refers to the presence of lime and not of calcium carbonate.

Rocks of the charnockite series are not met with until the outer edge of the Eastern Ghâts is reached, as at Táduru.

The kodurite series.

All the manganese-ore deposits now being worked are situated in the coastal plain country, and, as has been already explained elsewhere[1], are regarded as derived by chemical alteration from rocks of which the chief constituents are apatite, a manganese-garnet (spandite), manganese-pyroxenes (at least two species), potash-felspar, and quartz. This series is evidently quite different from the other series of rocks in this district, and in fact I am not aware that rocks of a similar character have been previously described. Hence, I propose to call this series the *kodurite series* after the Kodur mines where its constituent rocks are well exposed[2].

Relations of the kodurite series to the other crystallines.

From the foregoing it will be seen that the rocks of this area, including the outer fringe of the Eastern Ghâts, where also some occurrences of manganese-silicate-rocks have been detected, can be separated into the following petrological groups:—

1.	Kodurite series.	Igneous.
2.	Charnockite series.	
3.	Gneissose granite.	
4.	Calc-gneisses.	Metamorphic.
5.	Khondalite series.	
6.	Contact products of 2 and 5[3].	

The relative ages of these rock groups are difficult to determine; for they seem to be regularly interbedded one with the other, and clear sections showing the contacts of rocks of the different groups are rare. Dr. Walker, however, supposes the khondalite series, including groups 4 and 5 above, to be older than groups 2 and 3; for it was possibly the intrusion of these latter rocks that led to the metamorphism of ancient sediments into the rocks of groups 4 and 5.

The outcrops of the various rocks at the surface take the form of parallel bands, and, as far as has been revealed by mining operations, the

[1] *Rec. G. S. I.*, XXXIII, pp. 96, 97, (1906); *Trans. Min. Geol. Inst. Ind.*, I, pp. 87, 88, (1906).

[2] This name has already been announced in *Rec. G. S. I.*, XXXV, p. 22, (1907).

[3] T. L. Walker, *Rec. G. S. I.*, XXXVI, p. 1, (1907).

kodurite series forms no exception to this rule. The rocks of this series have nowhere been found in close relationship with the rocks of the charnockite series, except in the Eastern Ghâts; whilst their relations to the rocks of groups 3 to 5 are usually obscure. Except at Chintelavalsa and Táduru in the Eastern Ghâts their junctions with the neighbouring rocks are not seen at the surface. At the two localities just mentioned the kodurite rocks are not typical of the series; for they are composed very largely of the pyroxenic element. As will be seen from the sections given on Plate 55 and page 1114, the succession of rocks at these two places is as follows (in descending order) :—

Táduru.	*Chintelavalsa.*
1. Khondalite.	4. Calcareous gneiss.
2. Biotite-pyroxene-gneiss.	3. Manganese-silicate-rock.
3. Manganese-silicate-rock.	2. Biotitic gneiss.
4. Calcareous gneiss (scapolitic).	1*a*. Calcareous gneiss.
5. Gneissose granite.	1. Khondalite.

The numbers indicate what are probably corresponding horizons, if indeed such correspondence can be looked for in rocks of such antiquity at localities 5 miles apart. If this correlation be correct, it is clear that the rocks at one locality have been inverted. The rock overlying No. 4 at Chintelavalsa was unfortunately not observed. The evidence of these two sections, however, is that the manganese-silicate rocks are more closely associated with the calcareous or scapolitic gneisses and the biotite-pyroxene-gneisses (not observed elsewhere), than with either the khondalites or gneissose granites. Indeed, from the evidence of these two sections, one might suppose that the manganese-silicate-rocks are merely metamorphosed manganiferous sediments occupying a definite position in the succession of aluminous and calcareous sediments from which Walker supposes the khondalites and calcareous gneisses respectively to have been derived. The rock No. 2 contains a rhombic pyroxene, and Dr. Holland, to whom I showed the specimens and microscope slides, thinks it is probably a somewhat abnormal member of the charnockite series. At no other localities were such clear exposures seen, or the manganiferous rocks in such a fresh condition. All the other manganese deposits that I visited were situated in the plains, where alluvium largely obscures the geology, and where, had no mining been attempted, all that the geologist could see would be long low mounds of manganese-ore and manganese-silicate-bearing rocks conforming in their general direction to the strike of the ridges of khondalite, calcareous

gneisses, or gneissose granite, that crop out a little distance away on either side of the manganiferous outcrops, the intervening ground being covered by alluvial soil. At most of the localities visited, namely, the Kodur mines, Perapi, and Kotakarra II, calcareous gneisses were found cropping out on the low ground close to the manganese-ore band, whilst at the remainder, the following were the nearest exposed rocks :—

Garbhám.—Quartz-rock close to the deposit, garnet-bearing quartzites some 1,500 feet to the south, and gneissose granite some 1,500 feet to the north, of the west end of the manganiferous band.

Kotakarra I.—Coarse quartzite or vein quartz some distance away.

Avagudem.—Immediately to the north is a low ridge of white quartz and white garnetiferous quartzite passing to the east into a high ridge of khondalite.

Rámabhadrapuram.—In the excavations the manganiferous rocks are in contact with laminated quartzites, sometimes garnetiferous; whilst in another place, on the open ground between the Sonpuram and Mámidipilli workings, there is an outcrop of banded pyroxenic quartzite.

The only cases in which the mining operations have clearly revealed the rocks immediately adjacent to the kodurite rocks[1] are (1) at Devádа (page 1074), where the calcareous gneisses are seen in the excavations to form the western wall of the kodurite band; (2) at Perapi, where felspathic khondalite is seen to overlie the ore-band and associated felspathic rocks (page 1078 and fig. 83); and (3) at Rámabha drapuram, where quartzites are seen (above).

The quartzites (often garnetiferous) noted above as occurring in proximity to the manganese-ore bands may be regarded as forming a part of the khondalite series. Hence we see from the evidence given above that the bands of the kodurite series seem to be more closely associated with the khondalite series and the calcareous gneisses than with the gneissose granites. Regarding for the moment the khondalites and calcareous gneisses as forming a succession of metamorphosed sediments, it is seen that the evidence, scanty as it is, does not bear out the theory suggested by the Táduru and Chintelavalsa rocks that the manganese-silicate-rocks

[1] As will be explained later, the large masses of decomposed felspathic rocks that often form the immediate 'country' of the manganese-ore bodies and are well exposed in several of the quarries are considered to form a part of the kodurite series.

occur at any definite horizon in this succession. Sometimes they are most closely associated with the calcareous gneisses and sometimes with rocks of the khondalite series.

The kodurite series of igneous origin.

This prepares the way for the hypothesis that the rocks of the kodurite series are of igneous origin intrusive in the khondalites and the calcareous gneisses. As will be shown later, the chemical and mineralogical composition of these rocks point very strongly to their igneous (plutonic) origin. As they have nowhere been seen in contact with the gneissose granites it is impossible to say which is the older series. If the granites be the older then it is evident that the manganese-intrusives must have intruded themselves into the calcareous gneisses and khondalites as being less massive rocks. It is evident that with such well-bedded rocks as the calcareous gneisses and khondalites, the path of least resistance for the intrusions, would be, wherever the rocks were dipping at moderately high angles, along the bedding planes. This would account for the fact that everywhere the strike and dip, when observable, of the manganese-bearing rocks conforms to that of the neighbouring calcareous gneisses or khondalites. As an example of the way in which this intrusion may be supposed to have occurred, two alternative hypothetical sections across the Kodur kodurite-belt at Sandanandapuram are given on page 1053.[1] The second of these sections is constructed on the hypothesis that the kodurite intrusions took place subsequent to the consolidation of the gneissose granites. It may be thought that the very fact of the non-observance of any trespass of the kodurite series across the boundaries of the other rocks should be taken as an argument against the igneous origin of these rocks. It is therefore necessary to notice that—

(1) very few contacts of the kodurite series with other rocks have been noticed[2];

(2) the kodurite series has evidently, in at least some cases, such as Táduru, Chintelavalsa, and Garbhám (see fig. 88, page 1088), been subjected to earth-movements whilst included between the present wall rocks, and such movements would tend, especially if the rocks were still deeply buried in a region of high temperatures and pressures,

[1] See also *Trans. Min. Geol. Inst. Ind.*, I, p. 90, (1906).

[2] Even the Táduru and Chintelavalsa sections are constructed from the outcrops of the rocks and not from any clear section exposed by a stream cutting through the rocks.

to obliterate any minor evidences of intrusive relations, partly by rolling or crushing of the boundaries of the two rocks, and partly by reactions producing mineralogical re-arrangement at the junctions between rocks of different chemical composition, as in the case of the special rocks formed at the contacts of the charnockite and khondalite series in this very district[1]. But it must be admitted that in most cases there is little or no evidence that the kodurite series has suffered much from earth-movements since its presumed intrusion.

At Rámabhadrapuram there is exposed in one of the pits a band of quartz-microcline-rock which, since it contains the greenish blue apatite characteristic of the kodurite series, with which it is associated, may be supposed to form a part of this series. The structure of the rock is such as to suggest a pegmatite that has moved at the time of solidification.

The only remaining argument in favour of the igneous origin of the kodurite series is the presence of two large xenoliths of crystalline limestone in the masses of lithomargic rock at Kodur (see page 1065). Their position is best explained on the supposition that they are masses torn off and brought up from below by the kodurite intrusion.

The evidence in favour of the igneous origin of the kodurite series can therefore be summed up as follows :—

(1) The mineralogical and chemical composition of the rocks, which could only with difficulty be explained on any other hypothesis (see page 261).
(2) The signs of magmatic differentiation (see page 254).
(3) The supposed included xenoliths of crystalline limestone at Kodur.
(4) The pegmatoidal variety at Rámabhadrapuram.
(5) The varying horizon that the rocks of this series occupy in the succession of calcareous gneisses and khondalites.
(6) The fact that in two cases, Chintelavalsa and Táduru, they are also associated with rocks that probably belong to the charnockite series.

The only point that seems to be adverse to the igneous theory is the absence of any observed intrusive relations of the kodurite series with respect to the calc-gneisses and khondalites. This, as shown above, is easily accounted for.

[1] *T. L. Walker, Rec. G. S. I.*, XXXVI, p. 1, (1907).

Owing to the long continued chemical changes by which the manganese-ores have been produced from manganese silicates, the masses of the kodurite rocks as seen in mine workings are usually found to be extremely altered. In fact it is practically impossible to find perfectly fresh examples of any of the rocks of this series (except, perhaps, at the non-typical localities, Táduru and Chintelavalsa). Hence, one usually has to judge of the original composition of the kodurite rocks by carefully noting how in one place one mineral constituent has been decomposed, and in another place another constituent; and as the result of examining a large number of the many exposures to be found in the various workings, especially at Kodur, Garbhám, and Rámabhadrapuram, it has been found comparatively easy to arrive in this manner at the original mineralogical composition of the rocks of this series.

Nomenclature of the kodurite series.

The typical rock of the series is one composed of potash-felspar, manganese-garnet (spandite), and apatite, with or without pyroxene. This rock may be called *kodurite* when pyroxene is absent and *pyroxene-kodurite* when this mineral is present. When quartz is present the rocks can be distinguished as *quartz-kodurite* and *quartz-pyroxene-kodurite* respectively. A *biotite-kodurite* has been found at Rámabhadrapuram, this and a mica-bearing manganmagnetite-spandite-rock from Garbhám being the only mica-bearing examples of this series yet noticed[1]. The manganese-garnet may be regarded as the characteristic mineral of this series. To obviate the constant use of the cumbrous term *manganese-garnet* and to express the fact that this garnet, though probably very variable in composition, is intermediate between the manganese-alumina garnet, spessartite, and the lime-iron garnet, andradite, the term *spandite* has been coined (see page 163). Hence those rocks that are practically free from felspar may be called *spandite-rock*, *apatite-spandite-rock*, *pyroxene-spandite-rock*, etc., according to their composition. Those rocks composed mostly of pyroxene may be called *manganese-pyroxenites*; whilst those varieties that are free from spandite and pyroxene may be called *felspar-rock*, and *quartz-felspar-rock*, etc. There is also an *apatite-manganmagnetite-spandite-rock* containing a little *mica*; but it is uncertain if the manganmagnetite be an original constituent or not.

Although very little analytical work has yet been done on the rocks of the kodurite series, yet, on the basis of their mineralogical composition,

[1] The complex rock found at Chintelavalsa (see page 1114) also contains mica.

it is possible roughly to divide them into groups, according to what may be assumed to be the silica percentage of the particular rocks. The classification would be somewhat as follows :—

Quartz-orthoclase-rock. Apatite-quartz-orthoclase-rock. Quartz-kodurite in part.	Acid.
Quartz-kodurite in part. Orthoclase-rock.	Intermediat .
Kodurite. Pyroxene-kodurite. Biotite-kodurite.	Basic.
Spandite-rock. Apatite-spandite-rock. Pyroxene-spandite-rock. Manganese-pyroxenites. Graphitic manganese-pyroxenites.	Ultra-basic.

Many of these rocks grade one into the other as one mineral constituent becomes more abundant and another decreases in quantity. The rocks grouped as ultrabasic are non-felspathic, whilst all the others contain felspar, which is found to be a potash variety, probably orthoclase, wherever it is sufficiently fresh to be tested. Apatite occurs in smaller or greater quantities in all the rocks.

Pegmatite and vein quartz.

Intimately associated with the kodurite series are various varieties of vein-quartz and pegmatite. At Garbhám a very siliceous pegmatite clearly cuts the kodurite series; whilst at Kotakarra II, a quartz-felspar-pegmatite just as clearly cuts the kodurite rocks. These rocks may hence be supposed to be of subsequent age to the kodurite series. In some places, however, as at Kodur, small veins, not continuous for any length, are seen in the lithomarges. Their small extension may simply be due to the breaking up of more extensive veins by the slipping of the masses of lithomarge; but, in any case, one cannot help wondering if this quartz and some of the pegmatite be not the most acid varieties of the kodurite series. The apatite-bearing pegmatite of Rámabhadrapuram has already been referred to (page 248).

The minerals of the kodurite series.

The minerals so far found in the rocks of this series are :—Quartz, felspar, apatite, spandite, three or four manganese-pyroxenes (one of them rhodonite), biotite, graphite, and sphene, the three last-named minerals being of rare occurrence, and possibly mangan-magnetite. This is

neglecting, of course, all minerals, such as manganese-ores, lithomarge, and chert, that have been formed by subsequent alteration.

Quartz.—This is usually found in the most acid varieties of the series, and when it occurs the rock is as a rule sufficiently coarse-grained for the quartz to be about $\frac{1}{4}$ inch in diameter, the range for this constituent being usually about $\frac{1}{8}$ to $\frac{3}{8}$ inch. The quartz is white to colourless.

Felspar.—This is usually completely altered to lithomarge (kaolin), but is fairly often found forming a crumbly mass that gives a marked potash reaction. In rocks from Boiráni in Ganjám (page 255), however, it is found perfectly fresh, preserved in a matrix of secondary opal (see fig. 2, Plate 8). It then shows under the microscope the characters of orthoclase. A specimen of kodurite from Mámidipilli is a friable granular rock in which the constituents average $\frac{1}{8}$ to $\frac{1}{4}$ inch across, the felspar being fresh though very brittle. This also gives a strong potash reaction, and is seen under the microscope to be untwinned. The evidence therefore shows that the felspar is an untwinned potash variety and hence probably *orthoclase*. It is usually allotriomorphic, but in the granular rock from Mámidipilli mentioned above it is sub-idiomorphic, whilst in one specimen from Boiráni in Ganjám there is a porphyritic crystal (0·3 inch long) showing simple twinning.

Apatite.—This is the most universally distributed constituent, for it may be found in every variety of the rocks of this series. In some cases it is only seen microscopically; but it is frequently present in little rounded bluish-green prisms from $\frac{1}{16}$ to $\frac{1}{4}$ inch long, and can often be extracted in great abundance from the decomposed lithomarge that has been formed from the felspar of the original kodurite. At Garbhám, Rámabhadrapuram, and Devádа, it is especially abundant in this way. On page 1073 the find at Devádа of some hundredweights of deep sea-green apatite in rough prisms up to 5 inches diameter is noticed, and it is suggested that they may have been derived from a pegmatitic variety of kodurite. Analysis is said to have shown this to be fluor-apatite. On page 1063 is described the occurrence at Kodur of a veinlet of lavender-coloured apatite in spandite-rock. Both this and the Devádа crystals are mangan-fluor-apatite.

Spandite.—In the spandite-rock this occurs in granules averaging, at Kodur, $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter. As the grains are all in contact with one another they are bounded by flattish faces, which do not correspond to any particular directions. In kodurite the spandite is found both aggregated and in separate granules. These granules are usually

about $\frac{1}{16}$ to $\frac{1}{8}$ inch in diameter and are either well rounded or partly bounded by small unrecognizable faces. They often show a bright lustre and, on a fresh fracture, are seen glistening from the light-coloured matrix. The spandite varies in colour in the rocks of various localities from deep orange to orange-red and blood-red, and never shows the yellow and lighter orange colours of the spessartite of the Central Provinces. Under the microscope these garnets show various tints of pale-yellow, pale orange, and pale orange-brown.

Manganese-pyroxenes.—The least common of these is a rose-pink pyroxene, probably *rhodonite*. This is best seen at Chintelavalsa and Táduru, where it forms a coarsely crystalline rock composed of varying proportions of rhodonite and the other manganese-pyroxenes, with a certain amount of orange-coloured garnet. It is not certain whether there are only two other pyroxenes besides rhodonite, or three. These other pyroxenes are also best seen at Chintelvalsa and Táduru, where they form a coarsely granular rock with rhodonite. The supposed three varieties are brown, green, and brownish green, in colour, and an account of them is given on page 137. As the first-named is often of a rich orange-brown colour, it may easily be mistaken macroscopically for the manganese-garnet. The pyroxene seen at Kodur is usually entirely changed into a pseudomorph of soft brownish black manganese oxide still showing the cleavage of the pyroxene; but, where less altered, it appears to be blackish green. Until the manganese-pyroxenes of the various localities are critically examined it will be impossible to say how many species or varieties there are. At Kodur some of the altered forms of pyroxene are an inch and more in diameter.

Biotite.—This is found at Rámabhadrapuram and shows the ordinary pleochroism, brownish straw to dull orange-brown; it might, from its mode of occurrence, be expected to be manganiferous, but this point has not been determined. It also occurs at Chintelavalsa in a complex rock composed of spandite, rhodonite, green pyroxene, quartz, apatite, sphene, and graphite, and at Garbhám in apatite-manganmagnetite spandite-rock.

Graphite.—This is abundant in the Chintelavalsa rock noticed in the preceding paragraph. It occurs in scales up to $\frac{3}{4}$ inch diameter. It is also found in various rocks at Táduru (see page 1112).

Sphene.—The only occurrence is in the rock mentioned under 'biotite', in which it occurs in small crystals distinguishable only under the microscope.

Manganmagnetite.—On page 40 will be found an account of the apatite-manganmagnetite-spandite-rock of Garbhám. It is not improbable that this manganmagnetite is of primary origin, although the evidence one way or the other is not conclusive. In a series of rocks containing basic and ultra-basic members one would expect the presence of a black ore. In the ordinary basic and ultra-basic rocks such as gabbros and peridotites black ores are common, taking the form of ilmenite, magnetite, and chromite. In the case of the kodurite series we should expect any ore if present to contain manganese, and perhaps manganmagnetite would be the most likely mineral. Hence it is not unreasonable to suppose that the manganmagnetite of this Garbhám rock is an original constituent. As this mineral is often found in the manganese-ores of this area, the question naturally arises as to whether such manganmagnetite also is original, so that it is the only mineral left unaltered during the chemical changes by which the manganese-ores were produced; or whether it is, like the remainder of the manganese-ores, of secondary origin. There is at present no evidence available that will enable this point to be determined.

Petrology of the kodurite series.

I do not intend to give here any detailed description of the rocks of this series. A short account of the minerals has just been given and by reading this and the notices of the various rocks scattered through the descriptions of the deposits, a very good idea of the characteristics and mode of occurrence of these rocks will be obtained. Taken as a whole these rocks are of medium grain, being either of about the same degree of coarseness as an ordinary medium-grained granite, or of somewhat finer grain (constituents averaging $\frac{1}{16}$ to $\frac{1}{4}$ inch diameter). The apatites and garnets are often scattered as rounded idiomorphs in the remainder of the rock. The rocks do not usually shew banding, but at Táduru there is a distinct tendency to shew this characteristic, as also at Kotākarra.

It will, however, be interesting to consider the typical *kodurite*. As already stated this has nowhere been found unaltered. But as the processes of alteration have usually acted so as to affect different constituents at different places, it is easy to reconstruct the original rock. Judged in this way, the unaltered kodurite must have shewn red-brown garnet crystals, usually averaging $\frac{1}{16}$ to $\frac{1}{8}$ inch diameter, profusely scattered through a light-coloured matrix of white orthoclase (averaging $\frac{1}{8}$ to $\frac{1}{4}$ inch diameter), and greyish to greenish-blue rounded apatite prisms (averaging $\frac{1}{16}$ to $\frac{3}{16}$ inch diameter), the apatite being usually much less

abundant than the felspar. The garnets were both isolated and in little aggregates, and sparkled from the reflections from tiny faces, though on the whole they were rounded. The proportions of the constituents are, however, very variable so that it is not possible to give any definite chemical composition for the rock. Judging merely from appearances, the proportions by volume would be somewhat as follows in typical kodurites:—

Spandite	$\frac{1}{5}$		Spandite	$\frac{3}{8}$
Apatite	$\frac{1}{6}$	to	Apatite	$\frac{1}{4}$
Orthoclase	$\frac{1}{2}$		Orthoclase	$\frac{3}{8}$

there being every gradation from these to rocks composed entirely of spandite and apatite, or entirely of orthoclase.

Magmatic differentiation of the kodurite series.

On examining such mines as Kodur it is found that the more basic rocks, such as *spandite-rock*, occur as large patches and streaks, surrounded by zones of less basic composition such as *kodurite*, in a general matrix of *quartz-felspar-rock* or *felspar-rock*, the most acid members of the series. Assuming for the moment that the mineral composition of the rocks is sufficient to show that the kodurite series is of igneous origin, then it is found that the relations of its various members are easiest explained as being the result of magmatic differentiation, by which patches and streaks of the more basic rocks have separated out from the general magma, leaving the latter of a somewhat more acid composition than it otherwise would have been. It seems probable that this differentiation took place before the eruption of the magma and that the basic segregation patches thus formed were drawn out into streaks when the magma was intruded into its present position. Had the differentiation taken place after eruption we should have expected to find the more basic rocks located on the margins of the intrusions and the more acid rocks in the centre. The very opposite is, however, the case. Thus at Garbhám the ore-band, which corresponds to the original manganese-silicate-rocks, occupies a roughly central position with regard to the masses of lithomarge, corresponding to the original felspathic rocks, which form the north and south walls of the quarry (see figures 87, 88, pages 1087, 1088).

Localities for rocks of the kodurite series.

Occurrences of the various rocks of this series will be found mentioned in Part IV under the localities shown in the following list. This list will also give some idea of the relative abundance of the various rocks.

List of localities for the members of the kodurite series.

Quartz-orthoclase-rock.—Kodur, Devada, Perapi, Garbhám, Ávagudem, and Rámabhadrapuram.
Orthoclase-rock.—Kodur and Garbhám.
Quartz-apatite-orthoclase-rock.—Rámabhadrapuram.
Quartz-kodurite.—Devádа, Garbhám, and Rámabhadrapuram.
Kodurite.—Kodur, Devádа, Perapi, Garbhám, Kotakarra, Rámabhadrapuram.
Pyroxene-kodurite.—Kodur.
Biotite-kodurite.—Rámabhadrapuram.
Spandite-rock.—Kodur, Garbhám and Chintelavalsa.
Apatite-spandite-rock.—Kodur and Sandápuram.
Pyroxene-spandite-rock.—Kodur, Perapi, Chintelavalsa, and Táduru.
Manganese-pyroxenites.—Kodur, Chintelavalsa, Táduru, and Kantikapilli.
Graphite-bearing manganese-pyroxenites.—Chintelavalsa, Táduru.
Vein-quartz.—Kodur.
Pegmatite.—Devádа, and Rámabhadrapuram.

Ganjám District.

In view of the fact that the garnet contained in the specimen of rock from Boiráni, of which the calculated analysis is given on page 258, contains such a small proportion of manganese compared with the garnet found in the kodurite rocks of the Vizagapatam district, it seems at first sight doubtful if the Ganjám rocks be really the same series as the kodurite series of Vizagapatam district. Considering, however, the similarity of the rocks of the two areas in their other constituents and the fact that they both give rise to manganese-ore deposits on alteration and are otherwise subject to the same kinds of alteration, it seems probable that the two series are genetically the same, the only difference being that there is a considerable difference in the composition of the garnets contained in the rocks of the two areas as represented by the two specimens analysed. This difference may indeed be accidental and the analysis of a large number of specimens of these rocks from the two areas might show that there is a great variation in the composition of the garnets through the isomorphous replacement of one constituent of the garnet by another. But even if the manganese-garnets of the Vizagapatam rocks constantly contain a greater percentage of manganese than the manganese-garnets of the Ganjám district, the petrological and mineralogical resemblances of the rocks of these two areas are sufficiently close for them to be regarded as one and the same series until evidence to the contrary can be produced. Hence the term kodurite can be extended to the manganese-silicate-rocks of Ganjám.

Chemical Composition of Kodurite.

To get at the original composition of kodurite I picked out the two freshest examples I could find. One of these was a banded variety from Kotakarra in the Vizagapatam district. In this rock the garnet and apatite are still fresh, whilst the felspar has been entirely replaced by opal. Microscopic examination shows that this replacement by opal has been practically confined to the felspar, although a little garnet or apatite are perhaps occasionally affected. In the calculations given later on it is assumed that the replacement is entirely confined to the felspar. The rock usually shows small patches of black manganese oxides in places, but the piece selected was free from these stains. After prolonged soaking in water and finally boiling for some hours the specific gravity of this specimen was found to be 2·85[1]. This treatment was necessary because the rock was evidently porous and showed under the microscope numerous cavities in the opal; since some of these were perhaps closed, the specific gravity given above is probably a little lower than the value that would have been obtained if the specific gravity had been determined on the powdered rock. This was not considered desirable on account of the loss of particles through sliming that inevitably occurs when this course is pursued. This specimen, weighing 55·2 grammes, was then powdered up and the whole of it sent to Messrs. J. and H. S. Pattinson of Newcastle for analysis.

The other specimen was from Boiráni in the Ganjám district. It shows abundance of a light brown manganiferous garnet scattered through a matrix of opal in which are abundant remains of orthoclase felspar up to $\frac{1}{16}$ inch long. The opal is of greyish to greenish colour and translucent; and the apatite, since it is also of a pale greenish colour, is not easily distinguished in the hand-specimen from the opal. Under the microscope it is seen that the opal (with a little chalcedony) has been formed by the replacement of the felspar, and perhaps to a certain small extent by the replacement of the garnet, which is of a pale yellowish colour. The apatite is seen to be much less important in quantity than in the Kotakarra rock. A photomicrograph of this rock is given in fig. 2, Plate 8; it shows orthoclase, garnet, and opal. Some pieces free from black alteration products were selected and their specific gravity determined as before after prolonged boiling. This was found to be 2·65, which must also be a trifle lower than it would have been if determined

[1] I am indebted to Mr. K. A. K. Hallowes for this determination.

on the powdered rock. The pieces on which the determination was made weighed 16·35 grammes. The whole of them was powdered up and sent for analysis to the same firm of analysts as before. The results of these two analyses are shown below:—

	Opalized kodurite from Kotakarra.	Opalized kodurite from Boiráni.
	A. 233	A. 134
Manganese protoxide	10·00	1·07
Ferric oxide	6·07	4·79
Ferrous oxide	0·90	0·64
Alumina	11·50	10·59
Lime	11·67	13·87
Magnesia	0·14	0·26
Potash	0·01	4·00
Soda	0·18	0·36
Combined silica	35·50	32·25
Free silica	18·65	28·35
Phosphoric oxide	1·60	1·24
Cupric oxide	0·02	trace
Titanic oxide	0·32	0·27
Chlorine	trace	trace
Combined water	1·33	1·20
Moisture at 100° C	2·30	1·30
	100·19	100·19
Manganese	7·75	0·83
Iron	4·95	3·85
Silica (total)	54·15	60·60
Phosphorus	0·70	0·54

As the free silica in these rocks is present in the form of opal it is obvious that a portion of it has probably been returned as combined silica. This is confirmed when it is attempted to recalculate these analyses into terms of the mineralogical composition of the rock. In the first rock, since the alkalies present are so small in amount, I have put them aside as impurities, although it would probably be more correct to convert them into corresponding amounts of felspar. In the Boiráni rock, however, the potash present is considerable, and in this case

I have converted the alkalies into orthoclase and albite. The mineral composition of these two rocks works out as follows:—

Kotakarra rock. A.233			Boiráni rock. A.134		
Apatite		3·70	Apatite		2·87
K_2O		0·01	Orthoclase:—		
			K_2O	4·00	
			Al_2O_3	4·33	
			SiO_2	15·38	
				23·71	23·71
Na_2O		0·18	Albite:—		
			Na_2O	0·36	
			Al_2O_3	0·59	
			SiO_2	2·10	
				3·05	3·05
Manganese-garnet:—			Manganese-garnet:—		
MnO	10·00		MnO	1·07	
FeO	4·51		FeO	0·86	
CaO	9·57		CaO	12·24	
MgO	0·14		MgO	0·26	
Al_2O_3	11·50		Al_2O_3	5·67	
Fe_2O_3	2·10		Fe_2O_3	4·55	
SiO_2	22·76		SiO_2	15·22	
	60·58	60·58		39·87	39·87
Opal:—			Opal:—		
SiO_2	31·39		SiO_2	27·90	
H_2O	1·33		H_2O	1·20	
	32·72.	32·72		29·10	29·10
TiO_2		0·32	TiO_2		0·27
CuO		0·02	CuO		trace
Moisture		2·30	Moisture		1·30
Surplus oxygen		0·36	Surplus oxygen		0·02
		100·19			100·19

From each of the above analyses we can extract an analysis of the manganese-garnet by multiplying each of the constituents of the garnets by $\frac{100}{60{\cdot}58}$ in the case of the Kotakarra rock and by $\frac{100}{39{\cdot}87}$ in the case of the Boiráni rock. The results obtained are as follows:—

	The Kotakarra garnet.	The Boiráni garnet.
MnO	16·50	2·68
FeO	7·45	2·16
CaO	15·80	30·70
MgO	0·23	0·65
Al_2O_3	18·98	14·22
Fe_2O_3	3·47	11·41
SiO_2	37·57	38·18
	100·00	100·00

If the Kotakarra analysis be compared with the analysis of a specimen from Garbhám given on page 168 it will be seen that the two analyses are very similar, the only important difference being that in the Garbhám garnet a much larger proportion of the alumina is replaced by ferric oxide than in the Kotakarra garnet. In either case these garnets can be designated *spandite*, a contraction of spessart-andradite, indicating their intermediate composition. The Boiráni garnet, however, owing to its small percentage of manganese protoxide and high percentage of lime, must be regarded as intermediate between grossularite and andradite rather than spessartite and andradite, and consequently might be called on the same system grossular-andradite, or for short *grandite*. The use of this term is not, however, as necessary as that of spandite, for only one locality for the rocks of this series has yet been discovered in the Ganjám district.

Taking the analyses expressing the mineralogical composition given on page 258, it is possible by making fairly legitimate assumptions to arrive at the approximate original composition of the rock before alteration. Let us take first the Kotakarra rock. In this case we need only consider three minerals, apatite, spandite, and opal. Taking the specific gravity of the spandite to be 4·0 (G. of the Garbhám garnet was found to be 4·02), that of apatite to be 3·20, and that of the rock analysed 2·85, it is easy to calculate the specific gravity of the opal. This works out as 1·87. This figure is, of course, a little too low for opal, no doubt on account of the fact that the rock contains some closed spaces that were not filled by water, even after prolonged soaking, when the specific gravity was being taken. Hence the figure really represents the specific gravity of the opal and air spaces taken together. As has already been explained this opal has probably been formed by the replacement of the original felspar of the rock, which, judging from all the other occurrences of kodurite, must have been a potash variety probably containing a small percentage of soda in the form of microperthitic inclusions. By replacing the opal by orthoclase (G. = 2·57) the following works out as the original mineralogical composition of the rock:—

Apatite	3·70
Spandite	60·58
Orthoclase	45·44
TiO_2	0·32
CuO	0·02
	110·06

In the case of the Boiráni rock there are five minerals to be considered instead of three, namely apatite, orthoclase, albite, garnet, and opal. In this case, as no specific gravity determination of the garnet of this area is available, it is necessary to assume a figure for the opal and calculate the specific gravity of the garnet. Taking the specific gravity of the opal to be 1·90, of apatite 3·20, of albite 2·62, of orthoclase 2·57, and of the rock analysed 2·65, the value of this constant for the garnet is found to be 3·76, a considerably lower figure than for the Vizagapatam garnets, but one which is probably about correct. It is then necessary to reconvert the opal into the felspar that it has in all probability replaced. The original felspar, judging from the character of that still left, was probably orthoclase containing a small proportion of soda in the form of micro-perthitic inclusions. Assuming, for the sake of ease of calculation, that the original felspar was pure orthoclase, then the original composition of the rock works out as follows:—

Apatite	2·87
Orthoclase	63·07
Albite	3·05
Garnet (grandite)	39·87
TiO_2	0·27
CuO	trace
	109·13

Bringing both these analyses to 100 they may be re-stated as follows:—

	Kotakarra kodurite.	Boiráni kodurite.
Apatite	3·361	2·62
Orthoclase	41·29	57·80
Albite	...	2·79
Garnet	55·04	36·55
TiO_2	0·29	0·24
CuO	0·02	trace
	100·00	100·00
Specific gravity of original rock	3·23	2·92

[1] The apatite is lower in this analysis, than it would have been on a large sample of the rock: for the apatite is arranged in bands in the rock, and the apatite bands were scarce in the specimen analysed.

The figures showing the original specific gravity of the rocks were calculated from the mineral composition of the rocks given above. It is, of course, easy to turn these original mineralogical analyses into the original chemical analyses of the rocks, the results being as follows :—

	Kotakarra kodurite.	Boiráni kodurite.
SiO_2	47·45	53·36
Al_2O_3	18·00	16·31
Fe_2O_3	1·91	4·17
FeO	4·10	0·79
MnO	9·08	0·98
CaO	10·37	12·54
MgO	0·13	0·22
K_2O	6·97	9·75
Na_2O	(1)	0·33(1)
TiO_2	0·29	0·24
CuO	0·02	trace
P_2O_5	1·42	1·11
CaF_2(2)	0·26	0·20
	100·00	100·00

Assuming these reconstructed analyses to be approximations to the truth it becomes at once evident that it is very difficult to regard the rocks to which they correspond as anything else than of igneous origin. The difference between these rocks and the metamorphic rocks of the gondite series is at once seen by comparing these analyses with that of a piece of typical gondite shown on page 349.

1 There is probably a small percentage of soda replacing a part of the potash in the Kotakarra rock ; whilst in the Boiráni rock also a portion of the 9·75 of potash is in all probability replaced by soda, in addition to the 0·33 of soda, which corresponds to that shown in the original analysis.

2 The apatite is assumed to be fluor-apatite, although no fluorine is shown in the analysis.

CHAPTER XIII.

GEOLOGY—*continued.*

The Kodurite Series—*concluded.*

Alteration of the series and the formation of manganese-ores—Depth to which the ores extend.

The Alteration of the Kodurite Series and the Formation of the Manganese-ores.

Of the various localities that I visited, the Kodur Mines (Nos. 1 to 5), Perapi (No. 7), Garbhám (No. 11), Kotakarra (No. 12), Ávagudem, (No. 14), and Rámabhadrapuram (No. 20), showed the felspathic members of the kodurite series, with, at Kodur and Perapi, the manganiferous pyroxenites free from felspar. At Táduru (No. 21) and Chintelavalsa (No. 22), however, not a trace of felspar was to be seen in any of the manganese-bearing rocks, which are practically all manganese-pyroxenites. As these manganese-pyroxenites, except at the outcrops, seem to be perfectly fresh, no manganese-ores of any value are to be found at these two localities. But at all the other localities named above, namely those where the felspathic members exist, all the rocks of the kodurite series have been subjected to intense chemical action resulting in their partial or complete alteration. This chemical action has been so widespread that it is practically impossible to find in any of these mines a single piece of any of the rocks of this series that has not had at least one of its constituents attacked. The consequence is that, as noted in the previous chapter, it is only possible to deduce the original composition of the rocks of this series by observing the constituents that have escaped alteration in different parts of the workings and so determining the particular mineral that each constituent of the altered rocks represents. Moreover, it is frequently possible to find the fresh form of any given mineral passing into its altered form.

To follow out the chemical changes that have taken place it is necessary to know the chemical composition of each constituent mineral of the series. They are as follows:—

Quartz	SiO_2
Potash-felspar [1]	$K_2O.Al_2O_3.6SiO_2$
Apatite	$3Ca_3P_2O_8.CaF_2$
Spandite [2]	$3(Ca,Mn)O.(Al,Fe)_2O_3.3SiO_2$
Rhodonite	$MnSiO_3$
Other manganese pyroxenes	Composition not determined

[1] Assumed to be orthoclase.

[2] With small quantities of MgO and a very small amount of BaO

As rhodonite does not occur to any considerable extent in the deposits where economically valuable ore-bodies occur, it need not be taken into account. Further, the fact that the composition of the other manganese-pyroxenes has been left undetermined does not matter; for these constituents, although more abundant than rhodonite, are not sufficiently abundant in the majority of deposits to have given rise to any considerable proportion of the ore.

The changes that have affected the other minerals, as judged by the products of alteration left in the deposits, are, however, well worth consideration.

The replacement of quartz.

The quartz seems to a large extent to have escaped alteration, for it is to be detected as visible grains in much of the lithomarge. But it may to a certain extent have been dissolved and re-deposited as chert by the carbonated alkaline waters that decomposed the felspars (see below). It has also often been metasomatically replaced by manganese-ore (see fig. 1, Plate 13).

The alteration of the felspar.

Almost everywhere the felspar seems to have been converted into lithomarges. These are often stained yellow, brown, lavender, etc., owing to impregnation with oxides of iron; but they are sometimes pure white. One such white lithomarge was analysed by Mr. J. C. Brown (see page 1060), and, except for a little mechanically mixed quartz, was found to have the composition of pure kaolin; and probably all these lithomarges would be found on analysis to approach closely to this mineral, any deviations from the composition of kaolin being explicable as due to the presence of oxides of iron and manganese and of particles of quartz. The alteration of the felspar may be supposed to have been produced by the action of carbonated waters thus:—

$$\underset{\text{Orthoclase.}}{K_2O.Al_2O_3.6SiO_2} + CO_2 + 2H_2O = \underset{\text{Kaolin.}}{2H_2O.Al_2O_3.2SiO_2} + K_2CO_3 + 4SiO_2.$$

If these carbonated waters were not originally alkaline then they speedily became so by taking into solution the potash of the felspar. As is well known carbonated waters exert a powerful solvent action on silica, especially when it is in the gelatinous form in which it is so often liberated on the decomposition of silicates; these waters hence doubtless took into solution the silica released from the felspar in accordance with the above equation. In spots where the conditions were favourable this silica was often deposited in the cryptocrystalline or colloidal condition as chert or opal respectively;

The formation of chert and opal.

apparently much more frequently as the former, however, for large masses of chert, usually brown in colour, are to be found in almost every quarry (see pages 1065, 1079, 1089, for examples). The re-deposition of the silica seems often to have taken place by the metasomatic replacement of some or all of the constituents of portions of the kodurite mass. Where chert has been formed the replacement seems usually to have been complete; but where opal has been formed the replacement has been as a rule only partial, some chalcedony being usually formed as well. Example of replacement by opal occur at Kodur (see fig. 1, Plate 8; fresh spandite in a matrix of opal and chalcedony formed by the replacement of felspar, and of black manganese-ore probably representing original pyroxene), at Kotakarra (page 256, felspar replaced, garnet and apatite unaltered), and at Boiráni (page 256, garnets fresh, felspar partly fresh and partly replaced; see fig. 2, Plate 8). The potassium carbonate formed from the potash of the felspar must have been completely removed by the waters.

Potash removed in solution as carbonate.

Though many of the microscope slides of the rocks from various localities show that apatite suffers replacement by manganese oxide during the formation of the manganese-ores, yet no evidence has been found to show what becomes of the phosphorus and fluorine thus removed. From the evidence of the microscope there is no doubt that in many cases the phosphorus of the manganese-ores is at least partly due to the presence of residual apatite that has escaped replacement. But there is no evidence that this is always the case, and it is possible that some of the phosphoric oxide that must be set free when apatite is replaced, is taken up by the manganese-ore as oxide; or this oxide may be removed in solution and deposited in the ores at another spot. Apatite is, however, often a very abundant constituent of kodurite, sometimes forming as much as 10 to 30 per cent. of the rock. The manganese-ores of this area are, it is true, very phosphoric from the commercial point of view, since they range in phosphorus contents from about 0·25 to 0·50 per cent. But this, if present as fluorapatite, would correspond to a proportion of only 1·35 to 2·71 per cent. of apatite; whilst even 1 per cent. of phosphorus only means 5·42 per cent. of apatite. Hence it seems probable that all the phosphorus in the original apatite has not remained in the ores, either as apatite or oxide. Some of it must have been removed in solution together with the potassium carbonate derived from the felspar. The fate of the lime of the apatite must have been the same as

Alteration and replacement of apatite.

EXPLANATION OF PLATE 8.

PHOTOMICROGRAPHS.

FIG. 1.—The grey mineral showing high relief is the spandite. The remainder is opal with black stains of manganese oxide and clear central patches of chalcedony.

FIG. 2.—Comparatively fresh orthoclase is seen in the lower part of the photograph, and garnet in a matrix of opal with yellow stains of iron in the upper part.

FIG. 3.—The apatite is white. The remainder is spandite with secondary manganese oxide.

FIG. 4.—Spandite—white; psilomelane—black.

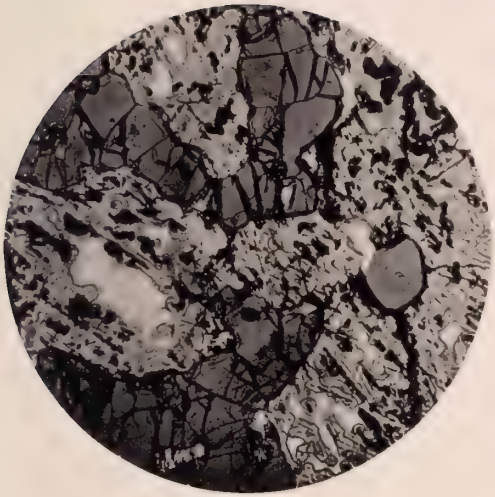


Fig. 1.—× 16.
Opalized kodurite.
Kodur, Vizagapatam district.

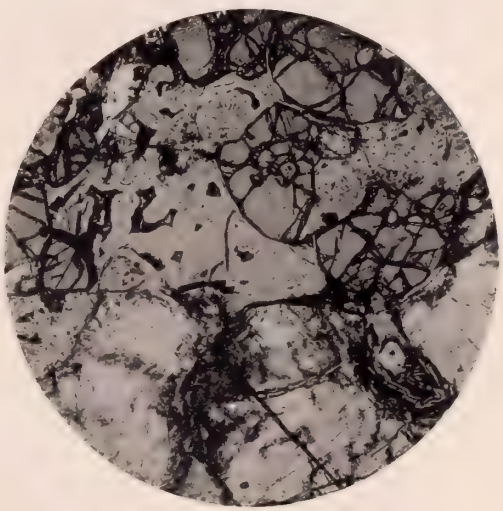
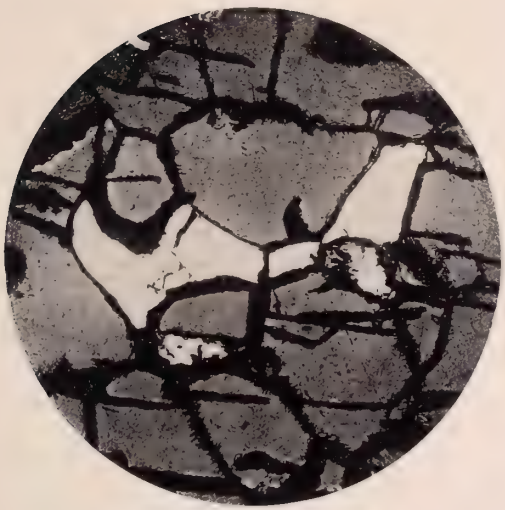


Fig. 2.—× 16.
Opalized kodurite with some orthoclase remaining.
Boiráni, Ganjám district, Madras.



L. L. Fermor, Photomicrograph.

Fig. 3.—× 16.
Apatite-spandite-rock.
Kodur.

Bemrose, Collo., Derby.

Fig. 4.—× 23.
Spandite (manganese-garnet), in psilomelane.
Rámabhadrapuram, Vizagapatam district.

that of the lime of the garnet, namely to be carried away as bicarbonate.[1]

Replacement of the spandite.

The manganese-garnet or spandite seems to be the most stable mineral in kodurite and many examples can be found of unaltered garnets in a matrix of partly or completely kaolinized felspar. When kodurite suffers replacement the garnet is usually the last mineral to be replaced, whilst it often escapes altogether, as in the rocks from Kotakarra and Boiráni (see fig. 2, Plate 8), where the felspar has been replaced by opal. When the replacement is effected by manganiferous solutions the felspar and apatite are often removed leaving perfectly fresh garnets in a matrix of psilomelane. Such garnet-studded psilomelane is especially common at Garbhám and Rámabhadrapuram (fig. 4, Plate 8). From this photomicrograph it will be seen, however, that the garnet is also beginning to be replaced by the psilomelane, veinlets of which are seen traversing the garnet. But the garnet itself also often suffers alteration, and although the manganese-pyroxenes have in some places provided a certain proportion of the manganese required for the formation of the manganese-ores, yet the major portion of the manganese has been derived from the garnets.

Alteration of spandite.

When kodurite is altered, the resultant rock is often crumbly lithomarge containing abundant scattered garnets and apatites. The alteration has, however, more often than not proceeded much further. The apatite has been completely removed whilst the garnet is still represented by little ochreous spots suggesting that the iron oxide is the last constituent of the garnet to be removed. The garnet from Garbhám analysed by Mr. J. C. Brown contains the following constituents (for complete analysis, see page 167):—

	Per cent.
SiO_2	35·24
Fe_2O_3	23·90
Al_2O_3	6·48
MnO	16·37
BaO	0·18
CaO	15·20
MgO	2·04
	99·41

The composition deduced for the garnet in the kodurite of Kotakarra is given on page 258.

[1] Both apatite and $Ca_3(PO_4)_2$ are known to be distinctly soluble in water containing CO_2 in solution. See A.M. Comey's 'Dictionary of Chemical Solubilities Inorganic,' page 298, (1896).

Now the alteration of the garnet must have been effected by the same agency, namely, carbonated water, as converted the orthoclase into kaolin. The action of such waters on a garnet of the above composition would be to remove the manganese and calcium, and the little magnesium, as bicarbonates, and to leave behind the alumina as kaolin, mixed with ferric oxide, the two forming the ochreous spots referred to above. The silica not required for the formation of the kaolin must, as in the case of the felspar, have been removed in solution and may also have contributed to the formation of the chert. It is shown on page 167 that a small portion of the iron oxide of the garnet was probably in the ferrous condition. This portion, 2·29 per cent. would also be removed as bicarbonate.

These manganiferous solutions circulated through the mass of kodurite rocks until perhaps they had taken up as much of the bicarbonates of manganese and calcium as the carbon dioxide in the solution would allow of. On now coming in contact with either fresh or decomposing kodurite they would no longer take up any more manganese.

Formation of manganese-ores by replacement of the kodurite rocks.

Now an examination of such a deposit as Kodur shows that although portions of the mass of rocks exposed are undergoing alteration on the lines explained above, yet there are other portions of the deposit in which the rocks are not being to any great extent kaolinized, but are instead suffering replacement by manganese-ore. The rocks that suffer this replacement may be divided into two groups, those, such as the quartz-felspar-rocks, that contain no manganese-bearing minerals, and those, such as kodurite, that contain a manganese silicate. I am of opinion that it is the saturated manganiferous solutions referred to above that cause the replacement of these rocks.

Replacement of the non-manganiferous varieties

Let us deal first with the non-manganiferous rocks. It is evident, both from an examination of the rocks *in situ* and from a study of specimens of the rocks macroscopically and under the microscope, that the whole mass of rock is undergoing a more or less complete replacement with the production of masses of manganese-ore, the purity of which depends on the extent to which this replacement has taken place. In some cases the rock to suffer replacement is the more or less decomposed quartz-felspar-rock or felspar-rock, the partial kaolinization of the rock having been no doubt effected by non-manganiferous solutions before the advent of the manganiferous solutions. The manganese-ore that first appears in this must

gradually grow by the continual segregation from the circulating manganiferous solutions of fresh quantities of manganese oxide; this being by preference deposited round the edges of, or in, the patches of manganese-ore already formed, rather than in parts of the rock in which manganese oxide has not yet been deposited. As a result of this irregular replacement many exposures are seen showing more or less kaolinized white quartz-felspar-rock or felspar-rock, with patches often many feet across that are black in colour due to a network of black manganese oxide, deposited along the boundaries of the grains of quartz and felspar, and in part replacing them. Here and there the replacement is complete, so that these black areas often contain irregularly scattered nodules and patches of merchantable manganese-ore, usually pyrolusite, but sometimes psilomelane. But the quantity of ore so formed is not usually sufficient to make it worth while to extract it, unless it is necessary to quarry the mass of rock in which it occurs as a part of the dead-work of the mine. Examples of this irregular replacement of the felspathic rocks are given in figures 85 and 86 on pages 1085 and 1086; and in fig. 4, Plate 13.

Minerals replaced by manganese-ore.

It is difficult to explain this and many other cases of replacement of one mineral by another in terms of chemical equations. But the examination of many hundreds of microscope-sections, hand-specimens, and exposures on outcrops and in mines, has convinced me that it is possible for a solution containing manganese salts to replace with manganese oxide almost any mineral. Amongst the minerals I have found thus replaced are iron-ores (hematite and limonite), quartz, calcite, felspar (orthoclase, microcline, and plagioclase), various micas, garnets, pyroxenes, and amphiboles, and apatite.

In the particular case of the replacement of orthoclase by manganese oxide noticed above, it is possible, assuming the manganese to be in solution as bicarbonate—as it would be, in accordance with what has been written on page 266, had it suffered no alteration in the meantime—, to explain the interchange by the greater affinity of carbon dioxide for potassium oxide than for manganese oxide. This interchange might then be expressed by the following equation:—

$$MnH_2(CO_3)_2 + 2(K_2O.Al_2O_3.6SiO_2) + O_2 = 2K_2CO_3 + 2Al_2O_3 + 12SiO_2 + H_2MnO_3.$$

Orthoclase.

In the presence of oxygen, probably present in solution, either in the manganiferous waters, or in water occupying the interspaces between the grains of mineral in the rock attacked, or less probably mechanically

retained in the gaseous condition in these same interspaces, the manganese would be deposited as one of the hydrated more highly oxidized forms, such as H_2MnO_3. If originally deposited as MnO or $Mn(OH)_2$ it would speedily be changed to a more highly oxidized form. The silica would be removed in solution in the alkaline carbonate. According to the well-known fact that alkaline carbonates precipitate aluminium hydroxide from solutions of aluminium salts, the alumina in the above equation should be left behind with the precipitated oxide of manganese, probably in the form of kaolin in combination with a certain proportion of the silica set free. The manganese-ores thus formed in these felspathic rocks do frequently contain a certain amount of alumina, but nothing like the quantity they should contain in accordance with the equation. It seems necessary, therefore, to suppose that under the conditions of temperature, pressure, and concentration, in which this replacement took place a large portion of the alumina was removed in solution in spite of the presence of carbonates. In this connection it must be remembered that all the chemical changes to which reference is being made in this section of this Memoir were probably effected by very dilute solutions and that a very slight solubility of the alumina would suffice for its removal.

The removal of alumina.

When the saturated manganiferous solutions hypothecated above come in contact with rocks containing manganese minerals, they can no longer assist in the breaking up of these rocks by dissolving further quantities of manganese and calcium from the garnet. On the other hand they probably begin to rid themselves of their burden of manganese by a more or less complete replacement by manganese oxide of the rock with which they come in contact. If the rock is kodurite, the commonest of the manganese-silicate-rocks, the felspar is replaced in the same way as in the case of the felspathic rocks outlined above. Sometimes the replacement seems to stop here and the product is manganese-ore, generally psilomelane, studded with bright orange-red or orange-brown garnets, as at Garbhám and Rámabhadrapuram. As the garnet itself contains manganese there is probably less tendency on the part of the manganiferous solutions to replace it by manganese oxide. Often, however, the replacement seems to go further than the substitution of the felspar and apatite and the garnet itself suffers replacement. As the solution effecting the change is depositing manganese oxide in the place of every constituent of the

Replacement of the manganiferous varieties.

rock that undergoes replacement, when the garnet is attacked the manganese it contains must be left behind with the manganese oxide deposited from the attacking solution. So that the resultant manganese-ore consists of the original manganese contained in the rock together with that brought in by the replacing solutions.

Formation of manganese-ores by alteration *in situ* of manganese-silicate-rocks.

Not only can manganese-ores be formed by replacement in the way described above, but they can be formed by the alteration *in situ* of the very highly manganiferous varieties of the kodurite series. This was to be well seen at the time of my visit to the Kodur deposit. In the north-east corner of the mine at the point A in fig. 82 on page 1060 there was exposed a mass of spandite-rock in every stage of alteration into manganese-ore, which was being actively quarried. The final product of the alteration is a vesicular psilomelane with numerous vesicles averaging about $\frac{1}{16}$ to $\frac{1}{8}$ inch in diameter. Some of these vesicles are found to contain water when freshly broken open, whilst others contain a brownish black powder, and some are filled with shining black braunite usually traversed by very thin veinlets of psilomelane. Since a common type of ore in this mine is massive grey psilomelane with small specks and patches of braunite, it seems probable to me that the vesicular ore mentioned above must be an intermediate stage between the garnet-rock and this massive ore, and that later the vesicles have become filled with braunite by percolating solutions of which we have evidence in the water contained in the cavities of the ore. I have alluded to this ore as having been formed by the decomposition of the spandite-rock *in situ*; but it is evident that, if this rock were decomposed and most of its constituents removed in solution except the manganese oxides and iron, the residue would be a porous mass of oxides and not solid manganese-ore. Hence it is necessary to suppose that a further portion of manganese was brought in in solution and added to that derived from the decomposition of the rock *in situ*. The question now arises as to whether manganese oxide was brought in after the spandite-rock had been decomposed with removal of most of its constituents except the oxides of manganese and iron; or whether the decomposition of the garnet and removal of certain of its constituents were effected by the same solutions as brought in the further supply of manganese oxide. For two reasons it is unlikely that the former is the case. In the first place, as carbonated alkaline solutions are supposed to account for the changes noticed in other parts of the deposit, it is necessary to suppose

that they also produced the decomposition of the spandite-rock. Had this decomposition taken place without the deposition of manganese brought in solution by the incoming waters, the results of the action would probably have been the same as have already been described as taking place when kodurite is attacked by these solutions, namely, the solution of the manganese and calcium as bicarbonates, leaving behind little else but the ferric oxide and any alumina in the garnet as kaolin. In the second place the rocks in this part of the mine show every stage of alteration from the comparatively fresh spandite-rock to good manganese-ore without any signs of the porous rock that would be formed if the decomposition of the garnet-rock took place separately from the introduction of manganese oxide from elsewhere. For these two reasons it is necessary to suppose that the solutions that effected the decomposition of the spandite-rock also deposited the manganese oxide brought in from outside. The solutions to produce this combined decomposition and deposition would be the alkaline carbonate solutions saturated with manganese bicarbonates. The reaction can be supposed to take place somewhat on the lines of the following equation :—

$$2[3(Ca,Mn)O.(Fe,Al)_2O_3.3SiO_2]^* + 3MnH_2(CO_3)_2 + 3O_2 + 6H_2O$$
Spandite.
$$= 6(MnO_2.H_2O) + 2(Fe,Al)_2O_3 + 3CaH_2(CO_3)_2 + 6SiO_2.$$

It will be seen that I have introduced oxygen into the above equation.

Alteration took place under oxidizing conditions.

It is not of course known whether the manganese was originally deposited in the protoxide condition and subsequently oxidized, or whether it was originally deposited in the more highly oxidized condition. In whichever condition it was deposited the oxide was probably hydrated, and in so far as it is now free from water has since become dehydrated. I think, however, that it was probably originally deposited in the higher state of oxidation ; in the first place because I think the formation is still going on to a certain extent, as for example at Kodur, obviously sufficiently near the surface to be within the range of oxidizing influences ; and in the second case because there seems to be no sign of any mineral, such as manganosite (MnO), pyrochroite ($MnO.H_2O$), or rhodochrosite ($MnCO_3$), in the lower state of oxidation, although these might have been formed and since entirely raised to the higher state of oxidation due to subsequent prolonged subjection to the influence of waters containing

* Ca and Mn assumed to be present in equal molecular proportions.

dissolved oxygen. It is interesting to notice that this deduction that the ores were formed under oxidizing conditions, meaning that they were formed comparatively near the surface, agrees with the conclusion, discussed later on, that kaolinization takes place comparatively near the surface. The calcium bicarbonate and silica shown in the foregoing equation would pass away in solution leaving a mixture of hydrated oxide of manganese with ferric oxide.

The removal of alumina.

The analysis of the Garbhám [1] spandite, which is very similar to that found in the part of the Kodur mine to which reference is made on page 269 shows 6·52 per cent. of Al_2O_3, whilst those of three pieces of manganese-ore, A.334, A.336, and A.338, from this same part of the Kodur mine show 1·38 to 6·84 per cent. of Al_2O_3, the mean value being 3·71 per cent. Now, owing to the removal of silica, as shown in the foregoing equation, we should have expected a small increase in the percentage of Al_2O_3, rather than a decided decrease. As it might be thought that the decrease shown above is fortuitous, and dependent on the specimens chosen for analysis, it is to be noticed that the calculated analysis of the Kotakarra garnet (page 258) shows 18·98 per cent. of Al_2O_3, and that the mean percentage of Al_2O_3 in 10 Vizagapatam ores of which the analyses are scattered through this Memoir is 2·50, the range being from 0·27 to 6·84. Some of the ores thus analysed may have been formed entirely by replacement; but in any case the point illustrated is that in whatever way the ores are formed there is a tendency for a disappearance of Al_2O_3. Hence the equation given above is not strictly true, because a portion of the Al_2O_3 is removed, probably by the same solution as decomposed the rock and deposited the manganese oxide. (Compare page 268).

We can regard the ores formed in this part of the Kodur mine as the combined product of the alteration of spandite-rock *in situ* and of the deposition of manganese oxide brought in from elsewhere; the deposition of this manganese oxide being probably somewhat of the nature of a replacement, in which the manganese contained in the solution attacking the garnet is deposited in the place of the constituents being dissolved.

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[1] It is a pity that no analysis of Kodur garnet is available. The Garbhám one was chosen because it happened to be easier to pick clean; but it looked exactly the same as the Kodur garnet. I have compared this analysis with those of the Kodur manganese-ores noticed above, because the Kodur ores are ones formed *in situ* from the garnet-rock; whilst this does not apply to the Garbhám ores analysed.

From what has been written above it is evident that the ores of the Vizagapatam district can be divided into three main divisions:—

The ores formed in three ways.

1. Those formed by the replacement of rocks, such as quartz-felspar-rock, not originally containing manganese. In this case all the manganese is of external origin.

2. Those formed by the replacement of rocks, such as kodurite, that contain a fair amount of manganese silicate, the manganese of the latter being added to that of the attacking solutions. In this case the larger proportion of the manganese is of external origin.

3. Those formed by the decomposition *in situ* of rocks composed almost entirely of manganese silicates, to the manganese of which a further portion, brought by the attacking solutions, is added. In this case about half of the manganese is of external origin.

It is difficult to say what proportion of the ores of this district have been formed by each method. In the Kodur mine ores of groups 2 and 3 probably predominate; whilst at Garbhám a considerable proportion of the ore has probably been formed by method 1, although ores formed by 2 and 3 still predominate. The ores formed by the different methods are not exactly the same and are shown below:—

1. Pyrolusite and psilomelane.
2. Psilomelane with some braunite.
3. Psilomelane with braunite as specks and patches.

In the equation given on page 270 it is assumed that all the ferric oxide remains in the manganese-ore. The spandite from Garbhám, of which an analysis is given on page 168, shows 21·28 per cent. of Fe_2O_3, whilst the percentages of Fe_2O_3 in the three ores from the part of Kodur mentioned on page 269 are 5·86, 6·57, and 13·14, with a mean of 8·52. This seems to indicate a removal of iron in solution. That this is probably not the case is indicated by a consideration of a larger number of analyses. Thus the Kotakarra garnet contains only 3·47 per cent. of Fe_2O_3, so that the mean of the two garnets is 12·37 per cent.; whilst the mean of the Fe_2O_3 in the 22 analyses of samples and pieces of manganese-ore from this district is 13·57 per cent.[1]

Ferric oxide in the ore.

[1] See foot-note to page 271.

Baryta in the ores.

An interesting feature of the manganese-ores of the Vizagapatam district is the baryta found in the 22 analyses referred to above. The amount of this constituent ranges from 0·03 to 9·53 per cent., the mean value being 2·03 per cent. Now according to the analysis of the sample of opalized kodurite, No. 233, given on page 257, and carried out by Messrs. J. and H. S. Pattinson, kodurite is to be supposed to contain either no barium at all, or such a small quantity that it cannot be estimated. Mr. J. Coggin Brown, however, found 0·18 per cent. of BaO in the specimen of spandite that he analysed, and possibly all spandite if carefully tested would be found to contain a trace or small quantity of this constituent. Since the amount of BaO in the original rocks is so small, the comparatively large quantity found in the ores cannot be simply residual, *i.e.*, have been left behind with the oxides of manganese and iron and a certain proportion of the Al_2O_3, when the garnets suffered decomposition. It is necessary to suppose that this was one of the constituents that went into solution, probably as bicarbonate; it must have been thus concentrated and later deposited during the formation of the manganese-ores. Unless, however, a much larger proportion of manganese passed into solution than was ultimately deposited as manganese-ore, it is difficult to explain the great increase of the BaO relative to the manganese oxides. If the supposition put forward in the former part of the previous sentence be thought to be unlikely, then it is necessary to suppose that the waters that originally attacked the masses of kodurite rocks brought in the barium oxide as a part of their burden, having obtained it from a source different to the rocks of the kodurite series.

Comparison with the Brazilian deposits.

It will be interesting to compare the Indian manganese-ore deposits of the kodurite series with those of the Queluz district, State of Minas Geraes, Brazil, the only ones, as far as I can discover, that bear any resemblance to those of Vizagapatam. Dr. Orville A. Derby[1], who has studied the Brazilian deposits, ascribes their formation in many cases to the decomposition and leaching of basic manganiferous rocks of which the most important mineral is manganese-garnet (spessartite). These masses of manganiferous rock often occur as dyke-like masses and are considered to be the result of magmatic segregation from a basic magma of dioritic, gabbroitic or noritic type, now represented by the very decomposed,

[1] *Amer. Jour. Sci.* XII, pp. 18-32, (1901).

and sometimes sheared, clay-like 'country' in which the manganese-ore bodies occur.

It will be seen that there is a general analogy between this theory and that which is supposed to explain the formation and structure of the Vizagapatam deposits of India. The analogy, however, only applies to the processes, *i.e.*, the magmatic segregation of the manganiferous rocks from a molten magma, with subsequent chemical changes producing the ore-bodies from the manganiferous-rocks and the clays (or lithomarges) from the less manganiferous 'country'—and not to the actual rocks concerned. For in Brazil the residual rock, left after the segregation from the magma of the manganiferous-rocks, was of basic character, while in Vizagapatam it was either a felspar or felspar-quartz-rock, *i.e.*, a more acid rock. The product of segregation in Brazil, moreover, was essentially a manganese-garnet rock sometimes containing an amphibolic (or perhaps pyroxenic) or micaceous mineral, and at other times instead of these latter free (original) manganese-oxide (? polianite) with ilmenite and rutile as accessories and a very small quantity of apatite, while both quartz and graphite, supposed to be subsequent introductions, also occur. This type of rock has been denominated *queluzite* by Derby. As shown in Chapter XII, *kodurite*, the typical product of segregation in the Vizagapatam area, is a considerably different rock of which the three chief constituents, apatite, spandite, and felspar, are all equally important.

The Depth to which the Manganese-ores extend.

There remains one very interesting question to discuss in connection with the alteration of the masses of kodurite rocks, namely, the depth at which this alteration took place. For on this depends the depth to which the bodies of manganese-ore may be expected to extend.

This problem is to be solved by a consideration of the depths at which the processes of kaolinization and oxidation occur. Let us deal first with kaolinization. Two different reagents have been invoked to explain this process. These are water containing carbon dioxide in solution, and water containing sulphuric acid. Waldemar Lindgren[1] says :—

Kaolinization.

'Apparently the pure aluminic silicate cannot be formed when the generating waters contain much carbon dioxide or alkaline carbonates. But it does form

[1] 'Metasomatic Processes in Fissure-Veins', *Trans. Amer. Inst. Min. Eng.*, XXX, p. 658, (1900).

under the influence of some waters containing a small amount of these reagents, and also in the presence of sulphuric acid, which, as is well known, rapidly attacks the feldspars.'

From the results of the reaction of the water on the rock concerned it can be said which of these two agents was contained in the waters. With carbon dioxide, orthoclase felspar is decomposed in accordance with the following equation :—

$$3K_2Al_2Si_6O_{16} + 6H_2O + 3CO_2 = 3(2H_2O.Al_2O_3.2SiO_2) + 3K_2CO_3 + 12SiO_2.$$
Orthoclase. Kaolin,

The alumina being insoluble in the presence of carbonates is left behind as kaolin, while the silica being soluble, is carried away in solution. With regard to water containing sulphuric acid Lindgren says [1] :—

'Silica is practically insoluble in solutions containing sulphates and chlorides, hydrogen sulphide and free sulphuric acid. Under these conditions, aluminum silicates are dissolved and sulphates or chlorides of aluminum are formed, with simultaneous separation of silica.'

Since, in the Vizagapatam manganese-ore deposits, a large portion of the silica has evidently been taken into solution and the alumina left behind as kaolin, the alteration of the rocks of the kodurite series has been considered on the preceding pages as due to the action of waters containing carbon dioxide in solution.

Vogt, writing on the same subject [2], says that the view held long ago by Forchhammer (1835) and Bischoff (1855), that kaolinization is due to the attack of water carrying carbon dioxide, must be the correct one for the following reasons :—

'(1) kaolinization is in many cases a surface process, affected by the weak carbonic-acid solutions of surface-waters ; (2) at somewhat greater depths, the feldspars of the rocks are often converted by similarly weak carbonic-acid waters into kaolin, sericite, etc., as well as calcite.'

On a later page [3] he mentions the three processes that are due to the action of waters containing carbon dioxide, or carbonates of alkalies, or alkaline earths, in variable proportions. These three processes are kaolinization, sericitization, and carbonatization :—

'In kaolinization, the waters carry so much carbonic acid that the alkaline and earthy carbonates are nearly or wholly removed, together with the dissolved silica. In sericitization and carbonatization, on the contrary, there is a deposit of potassium silicate or calcium carbonate.'

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1 'Metasomatic Processes in Fissure-Veins,' *Trans. Amer. Inst. Min. Eng.*, XXX, p. 664, (1900).

2 'Problems in the Geology of Ore-Deposits,' *Trans. Amer. Inst. Min. Eng.*, XXXI, p. 150, (1901).

3 *Ibid.*, p. 157.

Quite recently, Lindgren[1] has made the following remarks on the formation of kaolin :—

'The hydrothermal origin of large bodies of kaolin has been urged in several recent papers [2], by demonstrating the improbability of the formation of the mineral on a great scale by ordinary weathering and by indicating its connection with mineral deposits. Conceding this, it is nevertheless believed that kaolin is rarely formed by alkaline hot water at any considerable depth below the surface. Instances are multiplying (the occurrences at Cripple Creek among them) in which it can be shown that the kaolin of the upper levels exposed to oxidation changes into sericitic products in depth and that it is easily and abundantly formed by the action of solutions containing free sulphuric acid on sericitized metasomatic rocks and also, though less easily, on ordinary feldspathic rocks.'

Again, as there is no evidence that the felspathic rocks of the kodurite series of Vizagapatam have ever passed through the sericitic stage, there is no necessity to consider sulphuric acid as the reagent to which their chemical alteration is due ; but rather water containing carbon dioxide, reinforced by the addition of potassium carbonate as soon as some of the orthoclase had been decomposed by the attacking waters.

Oxidation.

From the foregoing extracts it will be seen that opinions differ as to the amount of carbon dioxide present in the solutions producing kaolinization ; but that it is agreed that kaolin is formed near to the surface rather than at considerable depths, and that, according to Lindgren, it occurs in the zone of oxidation, giving way to sericite at greater depths.

The zone of fracture and belt of weathering.

Now let us deal with oxidation. C. R. Van Hise [3] has divided the outer crust of the earth into three zones : an upper zone of fracture, a lower zone of flowage, and a middle zone of combined fracture and flowage.[4] The zone of fracture is that near the surface, and probably continues to a depth of about 3,000 feet. This upper zone of fracture is divided by Van Hise [5] into :—

'(1) an upper belt of weathering, and (2) a lower belt of cementation. The belt of weathering extends from the surface to the level of ground-water, and for

[1] 'The Relation of Ore-deposition to Physical Conditions,' *Economic Geology*, II, p. 120, (1907).

[2] Stutzer, *Zeitschrift für prakt. Geologie*, XIII, pp. 333-336, (1905).

[3] 'Some Principles Controlling the Deposition of Ores', *Trans. Amer. Inst. Min. Eng.*, XXX, p. 30, (1900).

[4] Van Hise elsewhere considers that the zones of fracture and flowage—divisions of the earth's crust based on structural considerations—correspond respectively to the zones of katamorphism and anamorphism—divisions of the earth's crust from the metamorphic point of view. See 'A Treatise on Metamorphism', U. S. Geological Survey, Monograph XLVII, p. 190, (1904).'

[5] 'Some Principles Controlling the Deposition of Ores', *Trans. Amer. Inst. Min. Eng.*, XXX, p. 72, (1900).

a variable distance into the sea of underground water. The belt of cementation extends from the bottom of the belt of weathering to the bottom of the belt of fracture.'

The distinction between these two belts is summed up by Van Hise [1] as follows:—

'The belt of weathering is characterized by disintegration and decomposition, carbonation, hydration and oxidation, by solution and decrease of volume. The belt of cementation is characterized by cementation and induration, by hydration, by deposition, and by increase of volume.'

The chief constituent dissolved out of the belt of weathering and transferred to the belt of cementation is silica formed during the decomposition of the silicates under the influence of water containing carbon dioxide.

From this it will be seen that the chemical changes, namely, carbonation and oxidation, characterizing the manganese-silicate rocks of the Vizagapatam district must have taken place since the rocks of the kodurite series came into the belt of weathering. The depth to which the zone of weathering extends at a particular locality depends on the level of ground-water at that locality. In general the ground-water level follows roughly the inequalities of the earth's surface. According to Van Hise[2]:—

Ground-water level.

'In regions of moderate elevation and moderate irregularities of topography the level of groundwater is usually from 10 feet to 100 feet below the surface. It is especially likely to be near the surface in regions where there is a thick layer of drift or a thick layer of disintegrated rocks. In elevated and irregular regions, and especially those in which the precipitation is rather small, the level of groundwater may be from 100 to 300 feet below the surface. In high, desert regions, and especially limestone regions, the level of groundwater may be from a thousand to several thousand feet below the surface.'

In the portion of the Vizagapatam district where the manganese-ore deposits are found, the topography is fairly flat, whilst the rainfall is moderate, namely 40 to 50 inches annually. Hence it is probable that the level of ground-water is fairly near the surface, probably much less than 100 feet below plain level. Hence, if the deposits were formed whilst the ground had its present configuration, we should not expect them to continue to any great depth below the surface before giving way to moderately fresh examples of the kodurite series. In the Kodur mine, however, a depth of some 90 to 100 feet below the level of the adjacent plains has already been reached. Now, although the level of ground-water probably lies higher than the bottom of this pit—considering the large amounts of water that continually enter it and

[1] *Ibid.*, p. 74. [2] *Ibid.*, p. 51.

necessitate constant pumping—, yet good ore is found to the very deepest parts of the quarry. Hence it would seem that the present ground-water level is higher than it can have been at the time of formation of the manganese-ores, so that we cannot rely on the present level of ground-water for information as to the depth to which the manganese-ore deposits may be expected to continue.

Time of formation of ores.

This means that the main mass of the ores was formed in the past, between the time when the processes of elevation and denudation brought the rocks of the kodurite series to the surface and the present. The last serious folding of the Archæan rocks of this area was probably contemporaneous with the folding of the Dhárwár rocks in other parts of India, which took place somewhere between the deposition of the Dhárwárs and the rocks of the Purána systems. It is probable that during this folding some of the rocks of the kodurite series were exposed at the surface. Their alteration may therefore have commenced in Archæan times and continued ever since, except for interruptions when the outcrops of the Archæan rocks were covered up by younger formations, such as perhaps the Purána formations and the Deccan Trap. No doubt denudation has been continuously removing the surface portions of the altered rocks, thus bringing deeper and deeper zones of the rocks nearer the surface and consequently within the influence of the carbonating and oxidizing waters.

Depth to which the ores extend.

Now the depth to which this alteration extended in past times depends on the maximum depth of the ground-water during the period in which the masses of kodurite rocks were exposed at the surface. In the absence of any information as to the climatic and topographic conditions of this region, between Archæan and historic times, it is not possible to say what was this maximum depth of ground-water in past times. Unless, however, this region was ever an arid region of very irregular and elevated topography, it is not likely that the ground-water level ever sank to the extreme depth of 1,000 and more feet characteristic of such regions. Let us assume that it was never at a depth of more than about 500 feet. Now, according to Van Hise, the zone of weathering may extend for some distance below the ground-water level. To allow for this let us put the maximum former extension in depth as 700 feet. Allowing for the denudation of an unknown amount of the surface portion of the kodurite rocks since the time when the ground-water level reached this maximum

depth below the surface, we can put the present depth of this former boundary between the belt of weathering and the belt of cementation as not more than 500 feet. As it is not probable that the alteration of the kodurite rocks accompanied by the formation of oxidized ores continued to any considerable depth below the bottom of the belt of weathering, we can take this figure of 500 feet as being a guess at the maximum depth to which the manganese-ores of this district may be expected to extend. It is obvious that as the assumptions on which this figure is based are merely guesses, it may happen that the ores continue to a considerably greater depth, or that they do not extend so deep. But in any case they probably extend deeper than it will be profitable to work them, considering the irregular distribution of the ore-bodies through the decomposed masses of lithomargic rock in which they occur.

The sources of the carbon dioxide.

There is one other point worth considering, namely, the source of the carbon dioxide that is supposed to have brought about the alteration of the kodurite rocks. This question of the source of the carbon dioxide that plays such a prominent part in the formation of ore-deposits is excellently summed up by Van Hise on page 96 of the paper already cited. Van Hise says:—

'I have already pointed out two sources for the excess of carbon-dioxide held in the underground waters. Where vegetation is abundant, carbon-dioxide is concentrated in the soil. A large part of this is retained in the belt of weathering by the process of carbonation of the silicates, but another part joins the sea of underground waters. Another source for the carbon-dioxide is that liberated from cavities within rocks. It is well known that in many rocks a large amount of carbon-dioxide is included in innumerable microscopic cavities. When such rocks are complexly deformed in the zone of fracture, the fractures must intersect many of these cavities, and thus liberate the carbon-dioxide. Where there are zones of crushing, that is, where there are trunk-channels for percolating waters, the amount of carbon-dioxide which may thus be liberated may be considerable. Another source for the carbon-dioxide is a process of silication',

which Van Hise has previously explained, in which the silica taken into solution in the belt of weathering, as the result of the decomposition of silicates by the carbon dioxide in the surface waters, percolates downwards into the belt of cementation and decomposes the carbonates of limestones and other rocks with the liberation of carbon dioxide.

'Therefore, deep-seated waters are ever receiving contributions of carbon-dioxide, and thus are continually more capable of taking metals in solution, until the waters reach conditions where silication does not occur.

In this process of silication alone is believed to be an adequate source of carbon-dioxide, so that metals may be carried as bicarbonates and the water also hold a further excess of carbon-dioxide.'

CHAPTER XIV.

GEOLOGY—*continued.*

The Manganiferous Rocks of the Dhárwár Facies, including the Gondite Series.

General—Deposition of the Dhárwár manganiferous sediments—Their partial metamorphism—Their more complete metamorphism—The alteration of the manganiferous silicates—Mineral veins and intrusives—Manganese-ores in crystalline limestones—Classification of the Dhárwár manganese-ores.

General.

The Dhárwár period of sedimentation.

It has already been mentioned that the formation of the oldest gneisses must have been followed by a period of mechanical sedimentation characterized by the deposition of sands, clays, and conglomerates. During the same period various chemical sediments must also have been deposited, particularly limestones, and possibly various ferruginous rocks, such as limonites. The period of tectonic quiescence during which these sediments accumulated must have been of considerable duration, and the sedimentation must have been interrupted at intervals by the eruption of contemporaneous lava-flows. Although the general period of sedimentation must have the same over the whole of what is now the Peninsula of India, yet it does not follow that this period of sedimentation began and ended at the same time in the various parts of the area. The whole of the series of sediments thus formed was then subjected to intense tectonic disturbances, by the action of which the sediments were folded in with the oldest gneisses more or less deeply and subjected to various degrees of metamorphism and consequent mineralogical and structural changes ; the degree of metamorphism produced naturally depending on the depth to which the particular sediments were folded in, that is on the intensity of the pressure and temperature to which they were subjected. In some cases this metamorphism was so pronounced that it is now extremely difficult to separate these rocks from the older rocks with which they are associated, so that the sediments of this period have to be mapped with the other Archæan rocks as the *metamorphic and crystalline complex*, as in the districts of Bálághát, Bhandára, Chhindwára, and Nágpur, in the Central Provinces, and in Nárukot in the Bombay Presidency. In

The metamorphism of the sediments.

other cases, where the metamorphism has been less severe, it is easy to separate off from the Archæan complex the rocks corresponding to the sediments of this period, as in the Panch Maháls, Belgaum, Dhárwár, North Kanara, Sandur, Mysore, Jabalpur, Singhbhum, and a part of Bálághát. The rocks thus separated from the Archæan complex were first known as *Transition* rocks, being grouped under this name with the Bijáwars and other rocks situated stratigraphically above the great Eparchæan interval. But they have since received local names in different parts of India. The area in which these rocks first received a local name is the Panch Maháls, where W. T. Blanford in 1869 [1] recognized that the rocks then classed as Transition or sub-metamorphic were in this area not the same as the Bijáwars of Central India and the Central Provinces. He consequently proposed the name *Chámpáner* for these rocks after the ruined Muslim city of that name, situated on the edge of the outcrop of these rocks. In 1886 R. B. Foote proposed the name *Dhárwár* [2] for the rocks of this facies situated in Dhárwár, Bellary, and Mysore, as it was not then suspected that they bore any similarity as regards age to Blanford's Chámpáner group.

The Transitions.

The Chámpáner series.

The Dhárwár series.

In the south of India the manganese-bearing rocks of the following districts have been recognized as Dhárwár in age :—Belgaum, Dhárwár North Kanara, Goa, Bellary, Sandur, Chitaldrug, Shimoga, and Tumkur. In a work published in 1891[3], Dr. King expressed the opinion that the rocks of Chutia Nágpur, previously designated by the convenient term 'Transition' are the equivalent of the Dhárwárs of Southern India. In 1904, whilst engaged in the examination of the manganese-ore deposits of the Jabalpur district, I came to the conclusion, as the result of a comparison of my specimens with those of other areas, and with the full concurrence of Messrs. Holland and Vredenburg, that the rocks of this area previously mapped as Bijáwars are really of Dhárwár age. Dr. Holland paid a special visit to this area to convince himself that the aspect of these rocks in the field supports the conclusion as to their age. When, in 1905, I visited the Chámpáner area, I was

1 *Mem. G. S. I.*, VI., p. 203.

2 *Rec. G. S. I.*, XIX, p. 98.

3 'Gold, Copper and Lead in Chota Nagpore and the adjacent country', by W. King and T. A. Pope. Thacker, Spink and Company, Calcutta, (1891), p. 3.

struck at once by the extraordinary lithological similarity of the Chámpáner rocks to those of Jabalpur and their consequent probable Dhárwár age.

The Chilpi Ghát series.

During 1904, I was able to examine yet another area of the rocks of the type once classed as Transition, namely, the series situated in the Bálághát and Raipur districts of the Central Provinces, which W. King, in 1885 [1], called the *Chilpi Ghát* series after the locality in which they were first examined. This series consists of quartzites, slates, conglomerates, and traps, in the parts where it was first examined. It was traced further west into the western portions of the Bálághát district by P. N. Bose, and it was here that I was able to examine it. The rocks have here become more metamorphosed, so that the slates have passed into micaceous phyllites and the conglomerates have been rendered schistose. The lithological similarity of these rocks to those of Southern India is so marked that Mr. Maclaren, who has had considerable experience of the Dhárwárs of the type areas, and to whom I showed my Chilpi specimens, fully agrees with my supposition that the Chilpi Ghát rocks are of the same age as the Dhárwárs.[2]

The metamorphic and crystalline complex of the Nágpur-Bálághát area.

The importance of this correlation is manifest when it is stated that very good evidence has been obtained that a considerable portion of the metamorphic and crystalline complex of the four districts of Bálághát, Bhandára, Chhindwára, and Nágpur, namely that with which the manganese-ore deposits are more particularly associated, really consists of portions of the Chilpis that have been so much more severely metamorphosed than in the areas further to the east that it has not yet been found practicable to map them separately from the other members of the metamorphic and crystalline complex.

It must be noticed that all the correlations of these ancient rocks in different parts of India are based on lithological resemblances. This correlation is, however, supported by the stratigraphical position of these rocks, namely, folded in with the oldest gneisses, and separated by the great Eparchæan unconformity from all the younger rocks.

The Arávalli series.

There is yet another area of metamorphosed Archæan sediments,—in Rájputána and Central

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[1] *Rec'. G. S. I.*, XVIII, p. 187.

[2] Since this was written I have been able to see for myself portions of the Dhárwárs of Southern India, and to further convince myself of the probable equivalence of the Chilpis and Dhárwárs.

India—where an attempt has been made to separate from the oldest gneisses a system of limestones, schists, and quartzites. To this the name *Arávalli* has been given, after the hills of that name to which the rocks of this formation give rise. It is probable that more than one series of rocks has been mapped under this name, but the major portion of the Arávallis is probably equivalent to the Dhárwárs of Southern India. The term Arvali or Arávalli was first adopted in 1877, by C. A. Hacket[1].

I have not had the advantage of visiting the typical Arávalli area, but have visited what must be an extension of this series in Jhábua State. My examination of the rocks found there in the vicinity of the manganese-ore deposit of Kájlidongri, and of specimens of this series from Rájputána, has shown me what a striking resemblance there is, both lithologically and, as far as I have seen, in mode of occurrence in the field, between the rocks of the Arávalli system and those of the Chilpi Ghát series of the Bálághát district, and the more metamorphosed equivalents of the Chilpis in the Bálághát, Bhandára, Chhindwára, and Nágpur districts of the Central Provinces. And, as has been already explained, the Chilpis are to be regarded as the equivalents in the Central Provinces of the Dhárwárs of Southern India. Hence we are driven to the conclusion that the series that have received the following names, arranged in order of priority, are roughly contemporaneous:—Chámpáner (1869), Arávalli (1877), Chilpi Ghát (1885), Dhárwár (1886), and portions of the metamorphic and crystalline complex of the Nágpur-Bálághát area, Central Provinces.

The equivalence of the various series.

With regard to the question as to which term is to be adopted in preference to the others, it is obvious that according to the rules of priority the term *Chámpáner* should be used. This, however, is the name that has been the least used of all, whilst that which has been extended to the largest number of areas, has passed into most general use, and is known best to geologists and miners, is the term *Dhárwár*, the familiarity of the name being largely due to the fact that the auriferous veins of Mysore are situated in the rocks to which this name was originally given. Since, however, the strict contemporaneity of these in various parts of India has not and never can be proved, partly because they are situated in isolated areas and partly because it does not seem probable that the sedimentation in the different areas can have

'Chámpáner' the prior term.

'Dhárwár' the most familiar term.

[1] *Rec. G. S. I.*, X, p. 84.

started and finished at exactly the same points of geological time, it will probably always be considered preferable to employ the local names with a general understanding as to their rough equivalence. When, however, it is desirable to treat the rocks of the different areas as a whole, it will be better to use the most familiar of the local names, namely *Dhárwár*, in preference to that which has priority on its side, but happens to be the least generally known of all, namely *Champáner*[1].

The term 'Dhárwár' adopted.

Now it so happens that, excluding the manganese-intrusives forming the kodurite series of Vizagapatam and Ganjám, all the manganese-bearing rocks of any importance that have been located in the great succession of rocks classed as Archæan are associated with rocks belonging either to the Dhárwárs or to one of the local groups shown above to be their equivalents. Hence the manganiferous rocks of this type will be grouped together, as *The manganiferous rocks of the Dhárwár facies or type.* A list is given on page 240 of the areas in which manganese-ores have been found in rocks of this facies.

The Deposition of the Manganiferous Sediments of the Dhárwár Period.

I now propose to give a general statement as to the mode of origin and occurrence of the manganese-ore deposits of the Dhárwár facies, and then in Chapters XV to XVII to explain this in detail with special reference to the occurrences in the Central Provinces and Jhábua, the areas with which I am most familiar and in which the most valuable deposits have been so far located.

On page 280 I have described the rocks of the Dhárwár facies as having been deposited as a vast succession of sediments, both mechanical and chemical, with the contemporaneous extrusion, in some areas, of lava flows. The evidence of the manganese-ore deposits shows that there must have been many basin-shaped areas formed in various parts of this region of deposition. Some of these basins must have been of large size, of the nature of large lakes or of small seas, whilst others may have

[1] My friend and colleague, Mr. E. W. Vredenburg, in an interesting booklet entitled 'A Summary of the Geology of India' (Thacker, Spink and Company, Calcutta; 1907), p. 17, considers that the term *Arávalli* should be adopted 'as it is derived from one of the most remarkable and one of the oldest physical features of the globe. There is super-abundant evidence, however, that these rocks correspond with those known in other parts of the globe as the Huronian, and the use of a local designation for the Indian area is therefore superfluous.' The treatment of the Archæan rocks in his book is very interesting, although I do not agree with it entirely.

been quite small. These basin-like areas were areas of deposition, both mechanical and chemical. Sometimes the incoming waters were comparatively clear and free from mechanically-carried material, such as sand or clay, but, instead, contained in solution salts of manganese. On reaching the masses of more or less stationary water the velocity of the incoming waters was checked, and, in the more or less still condition to which they were brought, the solutions were either subjected to atmospheric oxidation with the consequent formation and precipitation of oxide of manganese, or they were subjected to the action of reducing agents with the precipitation of the manganese in form of carbonate, or, much more improbably, of sulphide, according to the nature of the reducing agent. It is considered that the former alternative is in all probability the correct one, although the latter mode of deposition, namely, as carbonate, and possibly in very rare instances as sulphide, may have been locally operative, where the conditions of deposition were reducing instead of oxidizing, as must usually have been the case. As long as the incoming waters were free from silts the deposits accumulating on the bottoms of the basins must have been entirely chemical and composed of more or less pure oxides of manganese. But when the waters contained a moderate amount of silt, as well as the manganese salts, then the manganese oxides deposited must have been rendered siliceous by mechanical admixture with sand or clay. At other times, there must have been an alternate deposition of manganese oxides, either pure or impure, with layers of sand or clay partly or entirely free from manganese oxides; the layers of silt being deposited at times of flood, when the incoming waters had so diluted the manganese-bearing solutions with waters charged with silt that the sediments deposited consisted almost entirely of sand or clay. After the finish of the period during which manganiferous sediments were deposited, there came a time when the supply of manganese-bearing solutions ceased and the whole succession of manganese-bearing sediments was buried beneath a great thickness of sands, clays, and other sediments.

The source of the manganese.

The manganiferous solutions themselves must have been supplied from an area in which the rocks then subject to meteoric influences contained compounds of manganese liable to be decomposed under the action of such influences. For such a source we can probably look to some plutonic rock containing manganese-bearing silicates amongst its constituent minerals. The ordinary ferro-magnesian silicates usually contain small quantities of manganese, and this would no doubt be sufficient under

favourable circumstances to furnish the requisite quantities of manganese. It so happens, however, that there is in India a series of rocks, namely the kodurite series of Vizagapatam, that contains an unusually large amount of manganese as an essential constituent of its garnets and pyroxenes. There is no evidence available to show the relative ages of the kodurite and the Dhárwár series, but we must not lose sight of the possibility that the manganese deposited in Dhárwár times was derived, not from the small quantities of this element contained in the ferro-magnesian silicates of such ordinary rocks as granites or diorites, but from rocks specially rich in manganese ; and, if not actually from the kodurite series, then from some other series of rocks, equally rich in manganese, that has either been entirely buried beneath later rocks, or is in existence somewhere at the surface and yet awaits discovery.

The Partial Metamorphism of the Manganiferous Sediments.

After this vast succession of sediments had accumulated, or perhaps towards the end of their deposition, they (and all the older rocks) were involved in a prolonged and severe tectonic disturbance, which folded them in with the older rocks, and produced in them varying degrees of structural and mineralogical change according to the depth to which they were folded in, and consequently according to the intensity of the pressure and heat to which they were subjected. When the intensity of this metamorphism was not very great the clays were simply converted into slates or phyllites (usually referred to as argillites in Southern India) ; the sands were converted into quartzites or sandstone-quartzites of varying degrees of induration, often assuming jasperoid or hornstone-like characters, perhaps due to partial chemical solution and re-deposition ; whilst the conglomerates were rendered more or less schistose. Any ferruginous sediments were converted into hematite, and less frequently into magnetite, thus giving rise to the banded hematite-jaspers, often containing magnetite, that are so characteristic of the Dhárwárs. Any bands of manganese oxide that were contained in these sediments were compressed and rendered crystalline. The ores so formed may be termed *primary ores*. The rocks of the Dhárwár facies that have suffered this amount of metamorphism are the typical Dhárwárs of Dhárwár, Bellary, and Mysore, the Dhárwárs of Singhbhum and Jabalpur, the Chilpis of Bálághát, and the Chámpáners of the Panch Maháls. Of

Formation of primary ores.

Photo. by H. B. W. Garrick. *Calcutta Phototype Co.*

BANDED HEMATITE QUARTZITE; FROM KHATOLA, JABALPUR DISTRICT, C. P. THE JASPERY QUARTZITE BANDS APPEAR WHITE IN THE PHOTO, BUT ARE REALLY PINKISH.

the manganese-ores occurring in these areas, the following are considered to be primary ores:—(1) certainly those situated near the base of the Chilpi Ghát series in the Bálághát district of the Central Provinces, (2) probably a part of those of Sivarájpur in the Panch Maháls, and (3) possibly some of those of the Sandur Hills, although the available evidence is against this. Since the Dhárwár rocks have been exposed at the surface, other ores have been formed by the concentration of the usually small quantities of manganese contained in some of the Dhárwár rocks, such as the ferruginous members of the series. Such ores can be termed *secondary ores*; or as there is another, and much more important group of secondary ores, formed in all probability in depth in the Central Provinces and Jhábua, and considered on page 293, it will be better to refer to those formed on the surface as *outcrop secondary ores*, or alluding to their probable time of formation, *recent secondary ores*, whilst the ones formed in depth can be known as the *deep* or *Archæan secondary ores*.

Localities for the primary ores.

Formation of outcrop or recent secondary ores (lateritoid ores).

The most important occurrences of outcrop secondary ores are in the Sandur Hills and Mysore, practically all the ores of both areas in all probability coming under this heading. The source of the manganese was probably partly original phyllites and partly ferruginous quartzites. Amongst the outcrop secondary ores are those of Jabalpur, which have probably been entirely derived from the small quantities of manganese contained in the hematite of the hematitic jaspers by superficial alteration and concentration accompanied by the replacement of whatever rocks happened to be at the outcrop. Other outcrop secondary ores are those of Dhárwár, a portion of those of the Panch Maháls, in both of which the manganese may have been concentrated from limonitic jaspers; and a portion, and possibly the whole, of those of Goa, North Kanara, and Singhbhum. In the last case the immediate source cannot at present be referred to ferruginous rocks containing a small quantity of manganese, because such rocks have not yet been found in the immediate neighbourhood of the manganese-ore deposits. The outcrops of nearly all these ores have a laterite-like or *lateritoid* aspect, and in Belgaum, Goa, and Jabalpur, manganese-ores are also found in what seems to be true laterite resting on rocks of Dhárwár age. The distinction between the *lateritoid* ores and those in true *laterite* seems, however, artificial; because the field

Localities for outcrop secondary ores.

evidence makes it clear to me that both have been formed by impregnation and metasomatic replacement of Dhárwár rocks at the surface. [This statement does not apply to all varieties of laterite.]

I do not propose to give here any detailed account of the geology and origin of the Dhárwár manganese-ores of these less metamorphosed types.

These subjects are, however, touched upon in the description of each district, the fullest accounts being given for Jabalpur and the Sandur Hills. The lateritic and lateritoid ores are dealt with later under the heading of laterite (see pages 380 to 389).

The More Complete Metamorphism of the Dhárwárs.

When the intensity of the metamorphism to which the Dhárwár sediments were subjected was considerably more severe than described in the previous section, not only were the resultant structural changes more pronounced, but they were usually accompanied by a complete mineralogical re-arrangement or rather reconstruction of the rock. Sands were converted into vitreous quartzites in which any impurities crystallized out as definite minerals such as muscovite, hematite, garnet, or tourmaline, the formation of the last-named mineral possibly being due to the accession of various vapours to the mass of rock undergoing metamorphism. Very impure quartzites, grits, and conglomerates, often became completely recrystallized with the total obliteration of their original characters and the formation, in at least some cases, of gneisses, this change depending, of course, on the presence in the original sediment of a sufficient quantity of felspathic or other alkali-bearing material to give rise to the fresh felspars of the gneiss formed by metamorphism. Argillaceous sediments, such as clay, passed beyond the slate and phyllite stage and became entirely recrystallized as mica-schists, often crowded with various accessory minerals, such as rutile, tourmaline, and ottrelite. In the case of those deposits of manganese-ore that were originally laid down in the comparatively pure condition, the only effect of the metamorphism can have been to compress the ore into the smallest possible volume and consequently compel the various constituents of the ore to arrange themselves as the mineral aggregate that occupies the least volume, that is, to bring about the formation of the minerals of the highest specific gravity. Any

Primary manganese ores formed by the metamorphism of manganese oxide sediments.

siliceous material that had become mixed with the manganese oxides combined with them to form the crystalline and comparatively dense mineral, braunite, whilst the manganese oxides left over after all the available silica had been used up in the formation of braunite combined with the remaining impurities to form various manganates, which when mixed together isomorphously form the mineral psilomelane. This psilomelane forms the matrix in which the braunite granules are set, acting as a sort of cement to them. In the case, then, of comparatively pure manganiferous sediments, the chief difference between the ores produced by the less pronounced metamorphism noticed in the previous section and that noticed in this, lies in the fact that in the former case any silica mixed with the manganiferous sediments frequently remained after metamorphism in mechanical admixture with the manganese-ore, which was thus only able to assume the form of psilomelane; whilst in the latter case the intensity of heat developed was almost always sufficient to cause the formation of braunite, with the consequent production of a denser and more crystalline ore. There is, of course, every gradation between these two types, and both may be included under the term *primary ores* (see page 286).

Formation of the manganese silicates, spessartite and rhodonite, in the ore-bodies.

It is, however, in those bodies of manganese-ore in which there were layers of sand, clay, or other sediment, definitely interstratified with the layers of manganese oxide, or in which the ore-body consisted of manganese oxides rendered impure by the admixture of considerable quantities of sand or clay; and at the peripheries of the ore-bodies where the manganese oxides come in contact with the sediments forming the 'country' or wall-rock of the ore deposit, that the degree of metamorphism to which the rocks have been subjected is found to produce the greatest differences. As has already been explained, in the less metamorphosed type both the interstratified layers of silt and the 'country' of the deposits were simply converted into sandstone-quartzite, quartzite, slate, shale, etc., whilst the manganese oxides were compressed and rendered more or less crystalline. In the more metamorphosed type, however, the manganese oxides have interacted with any interstratified or admixed silt and with the 'country' or wall-rock. The product of this reaction has been various according to the nature of the silts and impurities. The chief products have been a manganese-garnet, and rhodonite, a manganese-pyroxene. The garnet approximates, as far as can be judged from two analyses, to the manganese-alumina-garnet, spessartite, the theoretical

composition of which is expresed by the formula :—$3MnO.Al_2O_3.3SiO_2$. As will be seen, however, from the analyses given on page 351, the manganese is usually partly replaced by calcium and magnesium, and the alumina by iron. The formation of the spessartite of the theoretical composition may be expressed by the following equation :—

$$\underset{\text{Kaolin or clay}}{2H_2O.Al_2O_3.2SiO_2} + 3MnO + \underset{\text{Quartz}}{SiO_2} = \underset{\text{Spessartite}}{3MnO.Al_2O_3.3SiO_2} + 2H_2O.$$

By the introduction of oxides of calcium, magnesium, and iron, representing calcareous, magnesian, and ferruginous impurities, respectively, in the original sediments, into both sides of the equation, the formation of spessartite containing these constituents could be shown. This shows that when the sediments admixed, interstratified, or in contact with, the manganese oxides were largely argillaceous, the chief mineral formed was spessartite. Any excess of quartz in these sediments over the kaolin crystallized out as quartz with formation of spessartite-quartz-rock, if all the manganese had already been used up in combining with the kaolin. Whilst, if any manganese oxide were still left over, it combined with this excess of quartz with the formation of the triclinic manganese-pyroxene, rhodonite, of the theoretical composition expressed by the formula $MnSiO_3$. No analysis has yet been made of Indian rhodonite, so that it is not possible to say if the manganese of this mineral is replaced by any other element to any considerable extent. Assuming the theoretical formula, the following equation will express the formation of this mineral :—

$$MnO_2 + \underset{\text{Quartz}}{SiO_2} = \underset{\text{Rhodonite}}{MnSiO_3}.$$

If, after this equation had been carried out, there were any silica left unaccounted for, it would crystallize out as quartz, and the rock then formed would be spessartite-rhodonite-quartz-rock. If the quantity of manganese were such that there would be an excess of manganese oxide left over after supplying that required to combine with all the sand and clay in the formation of spessartite and rhodonite, then the last portions of the silica, instead of forming rhodonite by combining with one molecule of manganese oxide for every molecule of quartz, would probably combine with a much larger quantity of manganese oxide with the formation of braunite according to the following equation :—

$$4MnO + 3MnO_2 + SiO_2 = \underset{\text{Braunite.}}{3Mn_2O_3.MnSiO_3}$$

The rock then formed would be a spessartite-rhodonite-braunite-rock, or a spessartite-braunite-rock, according as there had or had not been sufficient quartz to form rhodonite. In the event of the silts not containing any appreciable quantity of clay or other aluminous matter, no spessartite would be formed and the product would be rhodonite-rock, rhodonite-quartz-rock, or rhodonite-braunite-rock, according to the relative proportions of the manganese oxides and the silica. It will be noticed that in all the equations given above, except that for the formation of braunite, the manganese has been assumed to be in the protoxide form; but as has been already explained the manganese was in all probability originally deposited as the result of the oxidation of manganese-bearing solutions, and therefore presumably as the hydrated peroxide, H_2MnO_3. This simply means that during the changes described above oxygen must have been set free in the formation of spessartite and rhodonite, whilst in the formation of the manganese-garnet water must have also been liberated. If any appreciable quantity of the manganese was deposited as carbonate, then in the majority of cases this must have been broken up by interaction with other substances to form either oxide-ores of manganese or silicates of manganese, such as spessartite and rhodonite. In any case this breaking up can only have been accomplished with the evolution of carbon dioxide, as in the following equation showing the change by which rhodonite may have been formed from manganese carbonate:—

Liberation of water, oxygen, and rarely, of carbon dioxide.

$$MnCO_3 + SiO_2 = MnSiO_3 + CO_2$$

In a few cases manganese carbonate, in the form of the mineral rhodochrosite, has been found; but these are very few, the only cases known to me being the deposits of Gaimukh and Devi in the Chhindwára district, Central Provinces, and doubtfully the deposit of Pársioni in the Nágpur district, Central Provinces. But whether this rhodochrosite is to be considered as a remnant of that originally deposited at the time of deposition of the Dhárwár sediments, or whether it has been subsequently formed under the influence of waters charged with carbon dioxide percolating through the deposits, it is not possible to say.

As the result of the series of changes described above those bodies of manganese-ore that were originally deposited as solid masses of manganese oxides, without any large quantity of admixed silt, and free from interlaminations of sand or clay, are still found as solid masses

of manganese-ore; except at their peripheries, where they are separated from the practically non-manganiferous 'country' by an envelope of gneiss, schist, or quartzite, containing silicates more or less rich in manganese. These silicates have in some cases, no doubt, been formed by the interaction of the manganese of the ore-body with the surrounding 'country'; but in many cases the formation of these manganese-silicates must have been due to the fact that the sediments immediately over- and underlying the ore-body were mixed with manganese oxide at the time of their deposition, owing to a more or less gradual change from the deposition of manganese oxide to that of sand or clay, or *vice versâ*. As examples of such border products due to one of the causes outlined above mention may be made of the spessartite-bearing gneisses and quartzites occurring on either side of the ore-bodies at Kándri and Mansar in the Nágpur district; whilst the formation of the schist containing the manganiferous variety of amphibole to which the name of winchite has been given, at the Kájlidongri mine in Jhábua State, and of the schist containing manganiferous micas as one wall of the Sítapathúr deposit, are instances of this same phenomenon of the formation of manganese silicates at the periphery of a deposit, although neither deposits can be cited as an example of a solid mass of manganese-ore free from appreciable quantities of foreign material.

Formation of manganese silicates at the peripheries of dep sits.

On the other hand, those ore-bodies that contained intercalated layers of sand or clay have suffered great alteration. In cases where the alternating layers of ore and silt were thin, averaging, say, 1 to 3 inches each in thickness, the temperature and pressure to which they were subjected has often been sufficiently high to cause such a complete interaction between the ore-layers and silt that all the ore has been converted into spessartite or spessartite-quartz-rock; the resultant rock has a banded appearance owing to the alternation of bands of spessartiferous rock with bands of vitreous quartzite, roughly corresponding to the layers of manganese oxide and silt, respectively. When these layers were originally somewhat thicker the reaction may not have extended right to the centre of the ore-layer, so the central zone of a layer may consist of manganese-ore with, on each side of it, a layer of spessartiferous rock separating the ore-layer from other bands corresponding to the original layers of silt. In some cases the alternating layers of ore and silt may have been so fine that the whole mass of rock has passed into a more or less homogeneous mass of spessartite-quartz-rock, or of spessartite-rock practically free

The banded structure of the ore-bodies.

from quartz, the presence or absence of this constituent depending, of course, on the exact composition of the silt. Rhodonite is formed much less commonly, although it is to be found in almost every deposit where the degree of metamorphism has reached the point sufficient to bring about the formation of spessartite, the local presence of rhodonite at any particular point being simply determined by the actual composition of the silt and adjacent or admixed ore at that point. Other rarer silicates have also been formed in places, probably where the sediments or manganese oxides happen to have had an exceptional composition. The manganiferous sediments must also have contained a varying quantity of phosphorus, in what form it is impossible to say, but probably as apatite. Whatever was its original form, it is now found as apatite in the metamorphosed rocks, sometimes only in very small quantities, and sometimes, though rarely, in comparative abundance, as at Jothvád in Nárukot State, Bombay Presidency.

Apatite.

The Alteration of the Manganiferous Silicates.

The evidence collected at the various deposits in the Central Provinces shows that a considerable portion of this spessartite and rhodonite has been reconverted into manganese-ore. Many examples are to be found of rocks made up of these manganese-silicates traversed by veins and patches of manganese-ore. In some cases this alteration has become so complete that the fact that the ore was originally a rock made up of manganese silicates would not be suspected, were it not for the occasional find in the midst of a solid mass of ore of a residual patch of yellow spessartite or pink rhodonite. It might be suggested that this supposed residual manganese silicate is really a feature of the deposit due to the presence in the mass of oxides of patches of impurities, which, under the influence of metamorphic agencies, were converted into silicates. The evidence that such is not the case will be given later. Reasons will be given later (page 355) for supposing that this alteration of silicates to ore took place in Archæan times whilst the rocks were still at some distance from the surface. These ores can therefore be termed *deep* or *Archæan secondary ores* in contradistinction to the *surface* or *recent secondary ores* mentioned on page 287. Accepting for the present that it is certain that portions of the manganese-ore bodies have been produced by the

Re-conversion of spessartite and rhodonite into oxidized ores (deep secondary ores).

chemical alteration of manganese silicates, such as spessartite and rhodonite, the question at once arises as to what proportion of the ore-bodies as we now see them consists of the original manganese oxides simply compressed and to a certain extent recrystallized and what proportion of them consists of ores formed by the chemical alteration of manganese silicates. I have not yet found sufficient evidence to settle this question, but it seems possible to specify certain instances of either. Thus the solidity of the portion of the Kándri deposit in South Hill is such that it seems difficult to imagine that it has been formed solely by the chemical alteration and replacement of masses of spessartiferous or rhodoniferous rock; so that it seems more rational to suppose that this is an example of a mass of manganese oxide deposited as such and since compacted and recrystallized; but, considering that the saddle separating North from South Hill contains a large quantity of spessartite, it is possible that this deposit may after all have been formed by the alteration of manganese-silicate-rocks. The Bálághát deposit may, however, be cited as an undoubted example of a deposit that has not passed through the silicate stage, because it contains in it numerous bands of quartzite that have not been sufficiently metamorphosed to have even given rise to spessartite or rhodonite. As a good example of a deposit the ore of which has probably been derived, perhaps almost entirely, by the alteration of spessartiferous rock, the Mándri deposit may be cited, whilst the Mánegáon deposit, also in the Nágpur district, is a good example of a deposit in which the ore has been derived from both spessartite and rhodonite.

The question next arises as to when this alteration of the manganese silicates took place. It has already been shown that during the metamorphism of the manganese-ore deposits, water, oxygen, and probably, in some cases, carbon dioxide, must have been liberated. These substances would then have probably been available to act on the deposits as soon as the pressure was somewhat released, remaining in the meanwhile in the form of waters containing, as a portion of their burden, oxygen, and a certain proportion of carbon dioxide. Hence it seems probable that, as soon as the pressure became locally lessened, the percolating waters would begin to attack the manganese silicates. This attack must probably have continued for a considerable time after the cessation of the movements that folded and metamorphosed the Dhárwárs, probably in fact as long as the temperature was at any considerable elevation above that of water at the surface of the

Time of alteration of the manganese silicates.

earth. There is no evidence that this alteration is going on at the present day, except perhaps to a very insignificant extent.

Method of alteration of the manganese silicates.

Coming now to the way in which this alteration was effected, the evidence obtained by the microscopic examination of a large number of thin sections of spessartite- and rhodonite-bearing rocks in all stages of alteration to manganese-ore indicates that, in the case of spessartite, the mineral did not as a rule decompose *in situ* with the solution and removal of the alumina, silica, lime, and magnesia, and the resultant residual concentration of the oxides of manganese and iron. On the contrary, the garnet was attacked in one place with the solution of the manganese, which was carried in solution to another part of the deposit, where it replaced not only the spessartite already there, the manganese and iron contents of this replaced garnet being no doubt added to the oxides of manganese and iron brought in by the replacing solutions; but also the quartz, when the spessartite occurred as spessartite-quartz-rock. If the formation of the manganese-ore had been brought about by the decomposition *in situ* of the garnet and the accumulation of the manganese oxides, then the resultant ores would have been porous, unless further supplies of manganese had been subsequently brought in to fill up the interspaces. On the other hand, if the formation of the ore took place by replacement, as is suggested by the microscopic aspect of these rocks, the resultant ores should be compact, as is the case. Hence the evidence of the physical aspect of those ores that can fairly be supposed to have been derived from the spessartite-bearing rocks supports the theory that such ores were largely formed by replacement. But it must be noticed that this feature of the ores, namely, whether porous or compact, is not necessarily good evidence of the way in which they were formed, because their formation probably took place at such a depth that the pressure there existing may have been sufficient to close up any small open spaces and render the ores more compact than they would otherwise have been, though probably not as compact as an ore formed by replacement. In the case of rhodonite the ores seem to have much more frequently formed by the alteration of the mineral *in situ*, the alteration of the mineral starting along cracks and gradually spreading throughout the whole crystal. In cases where the rock contained both spessartite and rhodonite the latter mineral is frequently found nearly or completely altered to manganese oxides whilst the garnet remains perfectly fresh

Mineral Veins and Intrusives.

Percolation of mineralized waters during the metamorphism of the ore-bodies.

The waters that percolated through the masses of manganese-silicate-rock and manganese-ore towards the end of the folding of the Dhárwárs must, however, have contained many other substances in solution besides oxygen and carbon dioxide. In fact, if one can judge from the unusual minerals often found in the manganese-ore deposits at the present day, these waters must have contained arsenic, barium, and possibly some of the rare elements, as evidenced by the presence of arsenates at Kájlidongri in Jhábua and Sitapár in Chhindwára, by the almost invariable presence of small quantities of arsenic in the manganese-ores of the Central Provinces, and by the presence of barytes at Chárgáon in the Nágpur district. Moreover, probably during the folding, the Dhárwárs were at times fractured with the formation of fissures that acted as a passage for mineralized solutions. The best example of this phenomenon is at the Kájlidongri mine, where the ore-beds are traversed by a series of quartz veins containing barytes, a complex arsenate, and the manganate of barium, iron, and manganese, to which the name of hollandite has been given. The manganese-ores also frequently contain very small quantities of nickel and cobalt, and more rarely of copper, zinc, and lead. It is, of course, not possible to say whether these rarer constituents were present in the manganiferous sediments as originally deposited or whether they were subsequently introduced. It seems probable, however, that they were to a large extent introduced into the deposits during the time that they were being folded and subjected to high pressures and temperatures, this especially applying to the veins. The source of these introduced constituents was probably heated waters derived from masses of plutonic rock, whence they brought their metalliferous burden.

Veins traversing the ore-bodies.

Rocks intrusive in the ore-bodies.

In many of the deposits, as exposed in the mines, masses of pegmatite or other acid igneous rock are found, concerning the intrusive relation of which with regard to the manganese-ore bodies there is often unequivocal evidence. These intrusives would no doubt have solidified in the majority of cases as ordinary granite or pegmatite veins, had they traversed ordinary gneisses, schists, or quartzites. But in piercing the manganese-ore bodies they took the opportunity to absorb portions of the rocks through which they passed, with the consequence that when they solidified the absorbed

manganiferous material gave rise to minerals not usually found in such intrusives. Amongst such occurrences the following may be specified:—

1. The manganese-pyroxene, blanfordite, in a rock made up of quartz, microcline, and albite or oligoclase-andesine; at Rámdongri, Nágpur district.
2. Crystals of blanfordite, associated with juddite and braunite, in a rock composed chiefly of albite, but sometimes containing quartz as well; at the Kácharwáhi mine, Nágpur district.
3. A slightly manganiferous pyroxene, with pinkish brown to greenish brown pleochroism; at Kachi Dhána, Chhindwára district.
4. Crystals of yellow manganese-garnet in microcline-rock; at Beldongri, Nágpur district.
5. Yellow manganese-garnet in a pegmatite made up of quartz and felspar, the latter being usually either microcline or albite-oligoclase; at Sítapathúr, Bálághát district, and Bichua and Ghoti, Chhindwára district.
6. Red manganese-garnet in thin veins of granite made up of quartz and felspar (microcline, orthoclase, and oligoclase) traversing the manganiferous rocks; at Jothvád, Nárukot State.
7. A manganese-pyroxene showing the blanfordite type of pleochroism, in thin veins composed of intergrown microcline and oligoclase, with subordinate quartz. This rock also contains greenovite, the manganiferous variety of sphene; also at Jothvád.
8. Felspar (microcline)-braunite-rock with felspar crystal faces developed in cavities; at Sátak, Nágpur district.

Manganese-ores in Crystalline Limestones.

There is yet another mode of occurrence of manganese-ores in rocks that are probably to be regarded as an integral portion of the sediments deposited in Dhárwár times, namely that characterized by the occurrence of the ore in crystalline limestone in association with the manganiferous epidote, piedmontite. But I have separated these from the remainder of the manganese-ore deposits of Dhárwár facies, because they constitute a distinct mode of occurrence.

On pages 195 to 206 of a paper published in Volume XXXIII of the Records of the Geological Survey of India, I have given descriptions of various specimens of crystalline limestone collected in the Chhindwára

district of the Central Provinces, whilst on pages 168 to 172 of the same paper I have discussed the origin of these rocks. The crystalline limestones are there divided into three groups as follows:—

1. Limestones containing some or all of the following accessory minerals:—diopside, hornblende, tremolite, quartz, epidote, essonite, sphene, magnetite, and mica.
2. Manganiferous limestones, often containing spessartite and rhodonite, and black in colour due to the deposition of manganese oxide along the cleavage and twinning planes of the calcite.
3. Serpentinous limestones and cipollinos, usually dolomitic, and resulting from the chemical alteration of original white pyroxene-rock, sometimes containing phlogopite, and, more rarely, spinel and chondrodite.

It is not necessary to consider here whether the rocks from which the limestones of Class 3 are supposed to have been derived are of Dhárwár age, or a portion of the more ancient platform on which the Dhárwár sediments were deposited; for they have no connection with the manganese-bearing rocks. The Archæan rocks of this district have been so metamorphosed that they have all been mapped together as the metamorphic and crystalline complex, and no attempt has been made to distinguish the portions of this complex that are to be regarded as the equivalents of the Chilpi Ghát series of the Bálághát district, that is the portions that are of Dhárwár age. Consequently in the above-mentioned paper neither of the terms Chilpi and Dhárwár was used. It seems probable, however, that, of the rocks given in the classification on page 167 of that paper, Groups IV and V, and a portion of Group III, are to be regarded as belonging to the Dhárwár system; whilst, as will be explained below, the probability is that Groups VI and VII and the first two sections of Group VIII also belong to this same series of rocks.

Dhárwárs in the Chhindwára district.

The evidence put forward in that paper is held to justify the conclusion that limestones of Class 1 (above) have been formed by the chemical alteration of rocks similar to, or identical with, a group of rocks there called the quartz-pyroxene-gneisses. No analysis has ever been made of these gneisses, but a glance at the list of minerals they contain is sufficient to show that they may easily have been produced by the metamorphism of impure calcareous sediments. The alternative to this is to

The origin of the quartz-pyroxene-gneisses and crystalline limestones.

suppose that these gneisses have solidified from igneous fusion. Such a theory would, however, need the hypothecation of a magma of very unusual composition, so that it is preferable to suppose that they are metamorphosed sedimentaries. They may have been formed either during the Dhárwár period of sedimentation, or previously; but not later, for they have been involved in the Dhárwár folding. From their genetic relationship to the crystalline limestones, and the fact that one variety of these limestones is manganiferous and hence probably of Dhárwár age—although it is not impossible that some of the pre-Dhárwár sediments were manganiferous—it is probable that the sediments from which these gneisses may have been derived were deposited in Dhárwár times. Since the formation of the crystalline limestones is supposed to have been effected through the agency of alkaline solutions containing carbon dioxide, we must suppose that their formation took place during or towards the end of the folding of the Dhárwárs, when the rocks were at such a depth that they were at a high temperature and pressure, so that the conditions permitted of great molecular mobility. We can suppose that under the influence of the great heat and pressure the calcareous sediments were converted from impure limestones into calcareous gneisses with the expulsion of large quantities of carbon dioxide. The gas so expelled was probably kept in solution at a high temperature and pressure in the waters that must be present in all rocks at a great depth; and as soon as the intensity of the pressure and heat conditions somewhat abated these waters, charged, as they must have been, with alkalies in addition to the carbon dioxide expelled from the calcareous sediments on their conversion into gneiss, at once began to attack the recently-formed gneisses and reconvert them into limestones. Sufficient carbon dioxide would have been available to completely change the gneisses back into limestones had it all remained in the proximity of the gneisses until the conditions became suitable for this reconversion; but the mere fact that the reconversion was not completed shows either that a considerable portion of it was removed from the scene of action, no doubt in the ordinary course of circulation of the waters, before the time came for this reversal of the process by which it was set free or that if it all remained present the favourable conditions did not last long enough for the reconversion to be completed. This explanation will account for the fact that it is possible to find these gneisses in every stage of alteration into crystalline limestone, better than any other I can think of, and seems to be in complete accordance with the facts of occurrence and association of these rocks in the field. It has been introduced here

because various colleagues, on account of the plausible and probably correct theory that these very gneisses were formed by the metamorphism of impure calcareous sediments, have cast doubt on the reality of the passage of rocks similar to or identical with the quartz-pyroxene-gneisses into crystalline limestones. The theory outlined above shows that it is possible for impure calcareous sediments to have been first converted into very calcareous gneisses and then to have been partly reconverted into crystalline limestones. Moreover, this reconciliation of the two theories also allows for the case of pure or comparatively pure sediments being converted directly into crystalline limestones without passing through the gneiss stage. It must be noticed, however, that since the quartz-pyroxene-gneisses contain felspars, such as microcline and labradorite, both containing considerable amounts of alkalies, it follows that if these gneisses really were derived from calcareous sediments, the sediments must have contained considerable quantities of potash and soda.

The origin of the manganiferous limestones.

In the paper cited above the origin of the manganiferous limestones is not discussed, simply because at that time no evidence had been found to show whether their origin was the same or not as that of the non-manganiferous limestones with which they are often intimately associated. Subsequent microscopic work has, however, shown that their origin is the same.

These manganiferous limestones have only been found in the Nágpur and Chhindwára districts in the Central Provinces. In the Chhindwára district they contain spessartite and rhodonite, but no piedmontite, and are, moreover, of a dark brown to black colour owing to the secondary deposition of manganese oxides along the cleavage and twinning planes of the calcite[1]. At every occurrence in the Nágpur district, however, these limestones contain piedmontite, both in scattered grains and in nodules, the limestone matrix in which they are set being usually of a light colour and not blackened by the secondary deposition of manganese oxide, although the blackened limestones are also of frequent occurrence. The limestones as a rule also contain small bands and nodules of a brilliantly crystalline manganese-ore. Moreover, some of the nodules are of complex composition, consisting partly of piedmontite and partly of manganese-ore. The microscopic examination of these limestones usually shows crystals of piedmontite (Plate 10, fig. 4,) in a

[1] *Loc. cit.*, pp. 200, 201 ; and Plate 17, fig. 1

EXPLANATION OF PLATE 10.

PHOTOMICROGRAPHS.

FIG. 1.—Quartzite—light; manganese-ore—black.

FIG. 2.—The section shows piedmontite (dark) in a light-coloured matrix of plagioclase and orthoclase, with a certain proportion of apatite and quartz.

FIG. 3.—The black represents piedmontite, the grey is orthoclase, and the white is secondary calcite.

FIG. 4.—The dark mineral is piedmontite and the light is calcite.

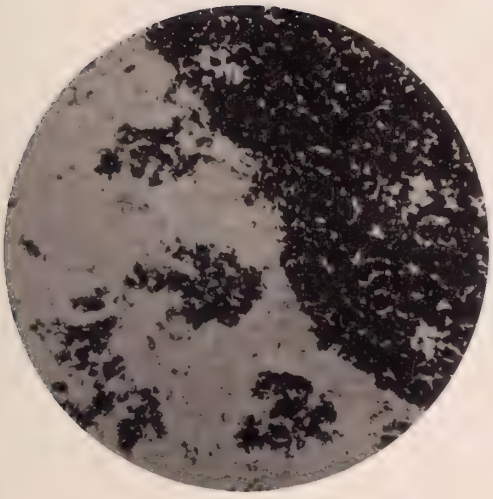


Fig. 1.—× 23.
Fine-grained quartzite being replaced by manganese-ore.
Sivarájpur, Panch Mahâls district, Bombay.

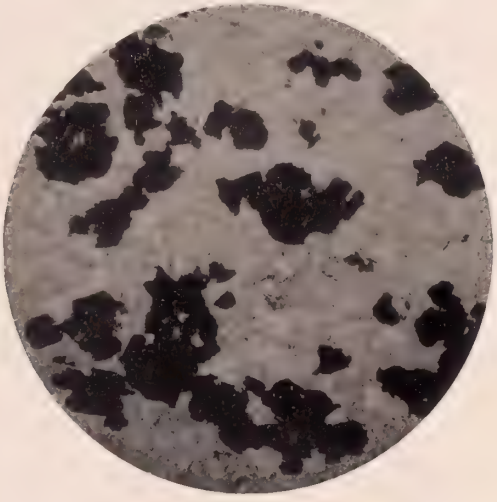
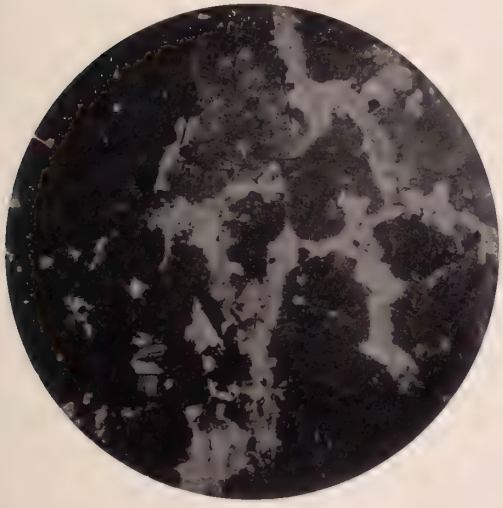
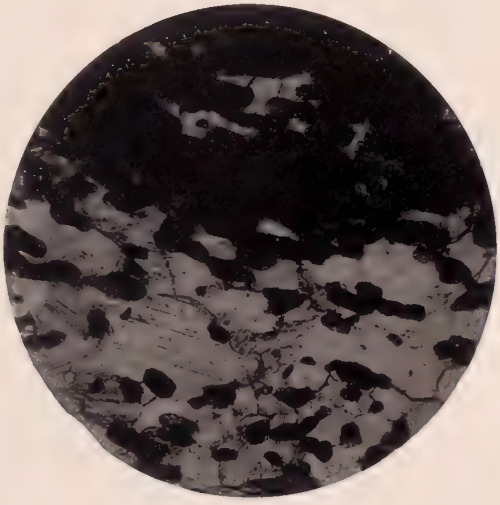


Fig. 2.—× 23.
Piedmontite-gneiss.
Páli, Nágpur district, C.P.



L. L. Fermor, Photomicrograph.

Fig. 3.—× 23.
Piedmontite and felspar, latter altering to calcite.
Ghogara, Nágpur district, C. P.



Bemrose, Collo., Derby.

Fig. 4.—× 23.
Piedmontite in crystalline limestone.
Ghogara.

matrix of calcite showing no signs of derivation from any other mineral; but, in one case, namely, Ghogara in the Pench river near Pársioni, I was fortunate enough to find an example of a piedmontite-bearing gneiss showing the same process of chemical alteration of felspar into calcite as I had so often found in connection with the non-manganiferous limestones. (Plate 10, fig. 3). I had collected this specimen as an example of a piedmontite-bearing limestone, so that it is possible that a far larger proportion of these supposed limestones are really gneisses, partially converted into limestones, than would be suspected from their appearance in the field. Piedmontite-gneisses were also found at Páli (Plate 10, fig. 2).

Piedmontite-gneisses.

Assuming that these gneisses are only metamorphosed sediments, the formation of the manganiferous limestones can be explained in the following way. During the deposition of the Dhárwár sediments there must have been periods when the sediments deposited were of a predominantly calcareous character. This deposition took place no doubt in water of some depth, such as the bottom of a sea or large lake. At times the deposition was only chemical leading to the production of pure limestones, but this must have been a rare case. Much more frequently a certain proportion of mechanical sediment was laid down at the same time, the proportion being sometimes very considerable, even as much as half the total deposit. In a certain number of cases, really forming but a small proportion of the whole, nodules, thin lenticular seams, and in a few rare cases small beds of manganese oxides, were deposited, probably in the same way as nodules of manganese-ore are being formed on the bottoms of the present-day oceans; namely, by some process of segregation, due to the power of a particle of manganese oxide, once deposited, to bring about the deposition round itself as a nucleus of small quantities of manganese salts dissolved in the neighbouring waters. The nodules and patches of manganese oxide, thus laid down, and subsequently covered up by a further deposit of calcareous matter, were no doubt often rendered impure by admixture with siliceous materials. In other cases, manganese must have been deposited with some uniformity throughout a considerable thickness of calcareous sediment, and in this case the deposition may well have been as carbonate. Then came the period during which the Dhárwár sediments were folded and metamorphosed. Those sediments that were sufficiently impure were converted into gneisses, of course with liberation of carbon dioxide and water; and in these gneisses the impurities

Theory of formation of the manganiferous limestones.

crystallized out as diopside, epidote, garnet, microcline, plagioclase, and sphene, etc. If the sediment contained a fair quantity of manganese, either as oxide or perhaps as carbonate, then the other impurities, instead of forming diopside, epidote, and ordinary garnet, gave rise to the corresponding manganiferous minerals rhodonite, piedmontite, and spessartite, of which piedmontite was by far the most frequently formed. The rhodonite and spessartite have not been analysed; but one would expect them to be more calcareous than the varieties found in the manganese-ore bodies previously considered, namely those that were formed by the metamorphism of the manganese-oxide sediments associated with non-calcareous sands and clays. There is no need to give equations for their formation as they would be very similar to those given on pages for the formation of non-calcareous spessartite and rhodonite. The formation of the piedmontite may be expressed by the following equation:—

Formation of piedmontite, spessartite and rhodonite.

$$2Mn_2O_3 + 2Fe_2O_3 + 5[2H_2O.Al_2O_3.2SiO_2] + 12CaCO_3 + 8SiO_2 =$$
$$\text{Clay (kaolin)} \qquad \text{Calcite} \qquad \text{Quartz}$$
$$= 6[Ca_2(Al.OH)(Al,Mn,Fe)_2(SiO_4)_3] + 12CO_2 + 7H_2O$$
$$\text{Piedmontite}$$

in which the Al, Mn, and Fe, are for the sake of simplicity assumed to be present in the group (Al, Mn, Fe) in equal molecular proportions. In cases where the segregations were mixed throughout with various impurities, the whole segregation was sometimes converted into piedmontite, often with the admixture of a little calcite or quartz or other impurity, the residue of the sediment mixed up with the manganese oxides. On the other hand, when the nodules, bands, or beds, of manganese oxide were deposited free or comparatively free from admixture with calcareous or other material, they were compacted on metamorphism into nodules, bands, or beds, of crystalline manganese-ore. As might be expected, many of the nodules, which is the commonest form that the segregations take, are of complex composition and composed partly of manganese-ore and partly of piedmontite. This may be due to the original segregations having been composed of manganese oxides in some parts free from, and in other parts containing, admixed impurities. On metamorphism the impure portions were converted into piedmontite and the pure portions into manganese-ore. In the specimen illustrated on Plate 14 one nodule is composed of manganese-ore inside with a peripheral zone varying from $\frac{1}{16}$ to $\frac{1}{32}$ inch thick of piedmontite. This peripheral zone

Nodules of manganese-ore and piedmontite.

was probably produced at the time of metamorphism of these rocks, by an interaction between the surface shell of the original manganese-oxide segregation and the surrounding calcareous sediment. I have not yet found evidence that any appreciable quantity of the manganese-ore found in the crystalline limestones has been produced by the subsequent chemical alteration of the piedmontite, so that it can for the present be assumed that by far the larger proportion of the ores occurring in limestones are the product of the direct compression of the originally deposited oxides of manganese. In cases where spessartite and rhodonite were formed, however, subsequent alteration has often taken place with the production of inferior ores. But as these two silicates have been much less frequently formed than piedmontite the ores so produced are not in sufficient quantity to be of much commercial value. Devi in the Chhindwára district may be instanced as a case of the formation of ores in this way. Subsequent changes have, however, often affected the piedmontite-bearing rocks. At every place where piedmontite limestones are found there is also found the black limestone, to the colouring of which by the deposition of manganese oxide along cleavage and twinning planes reference has already been made on page 300. In all these cases there seems to be a certain amount of spessartite and more rarely of rhodonite present, but it is not known whether all the manganese secondarily deposited in these black limestones has been derived from the spessartite or rhodonite, or whether the piedmontite has also contributed its quota. In one case, namely at Páli, in the Nágpur district, the limestone seems to have been bodily dissolved away with the formation of cavities in which beautiful crystals of pyrolusite have been deposited, the manganese required for this process having no doubt been derived from the manganese silicates contained in the adjacent limestones. In other parts of the same mass of rock at Páli the whole rock has been replaced by chert, in which are often found shining particles of manganese-ore formed previous to the silicification of the limestone by the conversion into manganese-ore of whatever manganese silicate happened to be in the limestone, more probably rhodonite or spessartite than piedmontite.

Alteration of manganiferous limestones.

Secondary formation of pyrolusite.

Manganiferous cherts.

The nodules of manganese-ore are not usually composed of one mineral only. Analysis shows that they are as a rule mixtures of braunite with a predominating amount of one of the manganates, hollandite or psilomelane. From

The mineral composition of the manganese-ores.

the frequently brilliantly crystalline character of the ores it is evident that the crystalline manganate, hollandite, is of common occurrence, the amorphous manganate, psilomelane, being relatively much less common than in the ordinary manganese-ore deposits of the Nágpur district.

Folding and faulting of manganese-ore bands.

At the exposure of crystalline limestones seen in the Pench river at Ghogara the nodular bands, often 1 to 3 feet long and only 1 to 3 inches thick, are often seen to be folded and faulted; in one case, in the small fault planes so formed, small flakes of a beautiful pink manganese-mica have developed. (See fig. 75 on page 963.)

Classification of the Manganese-ores Associated with the Dhárwár Series.

From the foregoing it will be seen that the manganese-ores of the Dhárwár facies can be divided into two main groups; those associated with the less metamorphosed type of Dhárwárs, and these associated with the more metamorphosed type to which the name of *the gondite series* is given on page 306. Each of these can be divided into secondary and primary ores. There are also the lateritic ores. I propose to now put forward a classification of all the manganese-ores of the Dhárwár facies, and to include in this classification the lateritic ores formed on the outcrops of Dhárwár rocks. It will be seen that this classification includes practically all the Indian manganese-ores, except those of the kodurite series and the lateritic ores formed on the outcrops of rocks, such as the Deccan Trap, that are not of Dhárwár age. In this classification I note in the right hand column the ores characterizing each method of formation. The names of the minerals are placed in order of importance in each case. In the case of the ores belonging to the divisions B.*a* and B.*c*, it is difficult to determine what proportion of the ores of the deposits of the areas given in B.*c* belong to each, and the distribution of the two minerals amongst the two groups may not be quite accurate. It will be noticed that the names of some of the areas come in two or even three places. As I have asterisked the occurrences that are at present (1907) being worked some idea can be formed as to which of the modes of occurrence in a particular area are of importance and which are not. I have not asterisked those ores that are quarried incidentally to the winning of other ores, but which by themselves are of no importance.

TABLE 22.

Classification, according to origin, of the manganese-ores associated with the Dhárwár rocks.

A. With the less metamorphosed type of Dharwars :—	
(*a*).—*Primary ores* :—	
Bálághát*	Psilomelane and pyrolusite ; rarely braunite and hollandite.
Panch Mahals*	
Singhbhum*(?)	
(*b*).—*Outcrop secondary ores* (*lateritoid ores*) :—	
Dhárwár	Psilomelane, pyrolusite wad, pseudo-manganite, and polianite(?)
Jabalpur*	
Mysore*	
North Kanara	
Panch Mahals.	
Sandur Hills*	
Singhbhum*	
B. With the more metamorphosed type of Dharwars :—	
(*a*).—*Primary ores* :—	
α. Associated with the gondite series. Probably some in nearly all the areas mentioned in c. α.*	Same as c. α.
β. Associated with crystalline limestones. Nagpur district*.	Hollandite, braunite, psilomelane.
(*b*).—*Outcrop secondary ores* :—	
α. Associated with the gondite series. Probably some in nearly all the areas mentioned in c. α.	Soft, dirty ores ; psilomelane and pyrolusite.
β. In cavities in crystalline limestone. Nágpur district.	Pyrolusite.
(*c*).—*Deep secondary ores* :—	
α. Associated with spessartite-and rhodonite-bearing rocks (the gondite series).	
Nárukot	Psilomelane, braunite, rarely hollandite, sitaparite, vredenburgite.
Jhábua*	
Bálághát*	
Bhandára*	
Chhindwára*	
Nágpur*	
β. Associated with crystalline limestones containing piedmontite, often spessartite, and rarely rhodonite.	
Chhindwára*	Psilomelane, braunite, and hollandite.
Nágpur.	
C. In laterite resting on the Dharwars :—	
Belgaum*	Psilomelane, pyrolusite, pseudo-manganite, and wad.
Goa*	
Jabalpur.	

CHAPTER XV.

GEOLOGY—*continued.*

The Gondite Series.

Origin and use of name—Areas where found—Nágpur-Bálághát area—Origin—Occurrence in Jhábua—In Nárukot.

Origin of the name.

In the foregoing pages a general account has been given of the manganese-bearing-rocks of the Dhárwár facies, in which the occurrences have been classified according to the degree of metamorphism they have suffered. Where the rocks have suffered the maximum amount of metamorphism they have often been completely reconstructed mineralogically, with the resultant production of many curious and interesting varieties. These can be distinguished with the utmost ease in the field from all the other rocks of the metamorphic and crystalline complex, and consequently, it has been thought desirable to bestow on these rocks a distinctive name for convenience both of reference and geological mapping. For this purpose the term *gondite* is proposed, the word being derived from the name of the race of so-called aboriginal inhabitants that is found over a large portion of the Central Provinces, especially those areas where the manganese-ore deposits are situated. The *Gonds* have already been once honoured in geological literature ; for the *Gondwána* system, the coal-bearing series of India, received its name from the country they inhabit. Further, this name has since been extended, in the form *Gondwána-land*, to denote a considerable portion of the earth's surface where rocks of similar age and characteristics are found. Owing, however, to the different form of the two words *gondite* and *Gondwána*, it is not considered likely that any confusion will arise in their use, even though the minerals that happen to characterize the *Gondite Series* and the *Gondwána System*, namely, manganese-ore and coal, respectively, are both black in colour.

Application of the name.

This term, like the term 'charnockite' introduced by Dr. Holland, and the term 'kodurite' proposed elsewhere in this Memoir, is only intended for the convenience of Indian geologists, and is not to be used outside the limits of the Indian

empire for rocks, apparently of the same character and age, without very strong evidence indeed of the strict equivalence of the rocks of the two areas. Moreover, it seems desirable at present that the term should only be applied to the most metamorphosed type of manganiferous Dhárwár rocks, namely those characterized by the development of manganiferous silicates. Of these highly metamorphosed rocks there are, as previously described, two divisions, namely the main division, characterized by the presence of spessartite-garnet and rhodonite, and the subordinate division characterized by the invariable association of manganese-ores with crystalline limestones, with the almost invariable presence of piedmontite (or possibly other manganiferous epidote). It is to the former division, characterized by the association of the manganese-ores and rocks with rocks formed by the metamorphism of non-calcareous sediments, such as sand, clay, or conglomerate, that it is at present proposed to restrict the term 'gondite'. Up to the present it has been found perfectly feasible to map separately the manganese-bearing rocks associated with a 'country' of mica-schist, quartzite, or gneiss, from those of which the 'country' is a crystalline limestone. Should later work show the impossibility of always clearly separating the two types of rocks it may then be found necessary for convenience of mapping to extend the term 'gondite' to the second group. In the meantime, they can be most conveniently referred to as the manganiferous limestones.

The areas in which manganese-ore deposits, or rocks belonging to this series, have been up to the present located are the following:—

Areas in which found.

1. Nárukot State, in the Rewa Kántha Agency, Bombay Presidency.
2. Jhábua State, in the Bhopáwar Agency, Central India.
3. The districts of Bálághát, Bhandára, Chhindwára, and Nágpur in the Central Provinces.
4. It is probable that the manganese-ore deposits that have been found in the State of Banswára in Rájputána are associated with rocks sufficiently metamorphosed to justify their inclusion in the gondite series.

The principal development of these rocks is in area No. 3, which will be referred to as the Nágpur-Bálághát area.

In discussing the relationships of this series with its 'country' it is necessary to depend almost entirely on the Central Provinces. The portion of

this province in which this series is located is occupied by a continuous stretch of Archæan rocks, beginning in the Chhindwára district in the extreme western part of the area, and extending thence in an easterly direction through the northern part of the Nágpur district and the southern part of the Seoni district. Thence the outcrop of this Archæan complex stretches to the east into the northern part of Bhandára and the western part of Bálághát. It also extends to the north into the Mandla district and to the south and south-east into the southern parts of Bhandára and Bálághát and into the Drug and Ráipur districts; but in these areas manganese-ores have not yet been located except for a doubtful occurrence in the extreme south of Bálághát.

The Nágpur-Bálághát area.

It is in the belt of Archæan rocks stretching from Chhindwára through Nágpur and Bhandára to Bálághát, that all the economically valuable manganese-ore deposits of the Central Provinces are situated. This manganiferous zone can be most conveniently designated the *Nágpur-Bálághát area.*

The total length of this manganiferous zone is about 72 miles from the Kachi Dhána deposit in the Chhindwára district on the extreme west to Jairási in the Bálághát district on the extreme east. It is only as far as Ukua in the Bálághát district, however, that the metamorphism is known to have been sufficiently severe to bring about the development of spessartite. In fact very little is known about the occurrences to the east of this point. The strike of this manganese belt averages east-north-east. Its maximum width is 15 miles, this being at the western end; whilst to the east of this point the width averages about 8 miles. This, however, is not, in all probability, the full width; for if the extreme northern parts of the Nágpur district, namely the forests lying to the north of Chorbáoli, and the adjoining southern parts of Seoni district, were properly prospected there is little doubt that further occurrences of the gondite series would be found[1].

The Origin of the Gondite Series.

With regard to the origin of the rocks of the gondite series, of which an account has already been given (pages 289 to 293), it is intended to give now an account of their relationships to the accompanying rocks to show that the theory there put forward is in all probability the correct one. In the first published account of the manganese-silicate-rocks of the Central

[1] Since this was written Mr. T. B. Kantharia has found manganese-ores at Korái Ghát. This place is about 26 miles N. N. E. of Chorbáoli and in the Seoni district.

Provinces[1] the opinion was expressed, it is true with considerable diffidence, that the manganese-bearing rocks of this area were intruded in the molten condition into the metamorphic schists, gneisses (and quartzites), with which the manganese-silicate-rocks are associated. This was written because it was then supposed that the manganese-garnets of Vizagapatam and the Central Provinces were the same and because in both areas the manganese-ores, at least in part, have been formed by the chemical alteration of the rocks containing these garnets. It was not then thought likely that there could be in one country, large though India is, two distinct series of rocks, each characterized by the presence of manganese-bearing garnets. The evidence derived from the study of the Vizagapatam occurrences in the field as exposed in the mines was so unequivocal in pointing to their igneous origin, that it was attempted to make the origin of the manganese-bearing rocks of the Central Provinces, which then seemed much more open to opinion agree with that of the manganese-bearing rocks of Vizagapatam. Since then, however, I have been able to make a much more careful microscopic examination of the Central Provinces rocks with the resultant abandonment of the igneous theory and a return to the theory that had first suggested itself in the field, namely that the manganese-silicate-rocks of the Central Provinces are metamorphosed sediments[2].

Evidence for igneous origin of the gondite series.

Since it has been found possible to ascribe an igneous origin to these rocks, even doubtfully, it will be as well to put forward here what evidence there is for that theory. In the first place, as the result of a careful piece of mapping at Rámdongri in the Nágpur district, it was found that the mass of manganese-silicate-rock forming hill No. 5 forked at its eastern end. (See the map of this area, Plate 24.) Moreover, the thin band of rhodoniferous rock running east from the bank of the Kanhán river strikes straight towards the main mass of this hill and apparently disappears just before reaching it. This may be due either to faulting or to a sudden thinning out of the band. Assuming, in either case, that this thin band corresponds to the huge lenticular swelling (as seen in plan) forming the main mass of hill No. 5, it was thought that this sudden change in the width of the manganiferous band could be easily explained on the hy-

[1] *Rec. G. S. I.*, XXXIII. p. 97. (1906); and *Trans. Min. Geol. Inst. Ind.*, I, p. 91, (1906).

[2] This change of views has already been put forward in the discussion on my paper 'Manganese in India' in the *Trans. Min. Geol. Inst. Ind.* I, pp. 228-231, (1907), and in *Rec. G. S. I.*, XXXV., p. 39, (1907).

pothesis that this mass of rock was an igneous intrusion that had been compelled to conform roughly to the strike of the associated rocks by being rolled out by tectonic movements subsequent to its intrusion. The forking of the mass of manganese-silicate-rock at the eastern end of this hill could then be explained as due to the intrusive relations of these rocks to the 'country'. [On the metamorphic hypothesis now adopted the forking would be explained as due to faulting, and the sudden swelling out of the manganese-silicate-rock in hill No. 5 as due to its having been originally deposited in a deep basin.] The absence of any signs of intrusive relations of the manganiferous rocks and ores towards the 'country' at every place except Rámdongri might be thought to more than overbalance the evidence of Rámdongri. But the pegmatitic and granitic rocks, about the igneous origin of which there can be no doubt, occurring in association with the manganiferous rocks, are also not as a rule clearly seen to be intrusive with regard to their 'country'. The general absence of felspar from the rocks of this series might have been considered sufficient to settle that they could not be of igneous origin. But this constituent is in a few cases present, although much more rarely than the macroscopic aspect of the rocks would lead one to suspect.

As the result, however, of a careful microscopic examination of a large number of thin slices of the rocks collected in this area, and the consideration of the chemical evidence that has since become available, it has become clear that these rocks are, as previously explained, metamorphosed sediments. A brief outline of the theory of their origin as thus revised is given in the two places, cited above. The evidence justifying this change will now be given.

Evidence for metamorphic origin of the gondite series.

In the north-east parts of the Nágpur-Bálághát area, namely those parts of the Bálághát district situated to the east of the Wainganga river, the manganese-ore deposits have been mapped as occurring in the Chilpi Ghát series of rocks, whilst to the west of this river they have been mapped as occurring in the metamorphic and crystalline complex. As has already been explained the latter type of deposit is characterized by the presence of various manganiferous silicates; whilst those mapped as occurring in the Chilpi series are sometimes free from such silicates, then containing only manganese-ores with associated and interbanded quartzites and phyllites. The key to the unravelling the relations of these two apparently different modes of occurrence of the manganese-ore deposits lies in the study of the Bálághát and Ukua deposits. A

reference to the map of this area (Plate 43) will show that these two deposits occur on one horizon, namely at or close to what has been mapped as the base of the Chilpis. At Bálághát the manganese-ore body consists of alternating layers of manganese-ore and red, black, and grey, vitreous quartzites. Underlying the ore-beds, and probably to be considered as a portion of the ore-body, is a variable thickness of a whitish jaspery quartzite, which often becomes so friable as to powder, when quarried, into a fine sand. This rests on a considerable thickness of schistose sericitic conglomeratic grits, which form the eastern slopes of the ridge on which the ore-band crops out. Overlying the ore-band is a great thickness of phyllites, which are often wrinkled and contorted and sometimes sufficiently crystalline to be called mica-schists. Frequently, on the other hand, they have not passed the slate stage. When phyllites, they are best designated sericitic phyllites. To the south-west this ore-band disappears beneath alluvium, but probably re-appears in Bálághát town in the form of a small outcrop of manganese-ore, which I am told occurs there, but which I have not personally seen. To the south-west of this, the band again gets hidden, at least for some distance. To the north-north-east, however, the band can be traced along the ridge until it dies out, first passing into a limonitic rock. Some 10 miles to the east-north-east this band reappears at what must be its wonted horizon, namely the base of the Chilpis as here mapped. From this point the ore-band has been traced continuously through Ghondi, Gudma, Ukua, and Samnapur. I examined it in the last three village areas and made the interesting discovery that the 'country' of the manganese-ores is similar to that of Bálághát, but considerably more metamorphosed. The phyllites of Bálághát have here become proper crystalline mica-schists, whilst the manganese-ore band contains yellow manganese-garnet, developed, no doubt, by interaction between manganese oxide and interbanded or admixed argillaceous and siliceous materials. But the most remarkable feature of all is the rock underlying the ore-body. At first sight one calls this without any hesitation 'gneiss', and the rock seems to be an ordinary micaceous gneiss, such as one so frequently meets with in the metamorphic and crystalline complex. But on careful examination what seem to be pebbles of white quartz

The rocks at Bálághát and Ukua.

Conglomeratic grit converted into gneiss.

and granite are found weathering out at the surface of the supposed gneiss. On breaking the rock at such places it is found that the projections are in truth pebbles. They are composed of various materials, white quartz, granite, and gneiss, and are set in a matrix having the ordinary mineralogical composition of a micaceous gneiss. Under the microscope this matrix is seen to be much strained and granulitized and composed of quartz, microcline, plagioclase, and biotite, with often muscovite. The conclusion that seems unavoidable is that this conglomeratic gneiss is only a metamorphosed conglomeratic grit, no doubt very impure, equivalent to the rock of this character, already schistose, that underlies the ore-band at Bálághát. That such a rock can be formed by the metamorphism of an impure grit has been conclusively shown by E. H. Cunningham-Craig [1] writing of the rocks of the Loch Lomond district in Scotland. He shows that albite-gneisses have been formed from the group of rocks known as the Beinn-Ledi Grits by dynamic and constructive metamorphism. We seem to have in the Bálághát district an analogous case, the only difference of note being that in the area examined by Cunningham-Craig the increasing metamorphism has taken place across the strike, on passing from one fold of the grits to another that has been subjected to a higher degree of pressure, and to a certain extent, temperature ; whilst in the Bálághát district the passage from grit to gneiss has taken place along the strike. We thus see that the rocks of Bálághát and Ukua can be correlated as follows :—

Bálághát.	Ukua.
1. Phyllites with subordinate slates and mica-schists.	1. Mica-schists.
2. Manganese-ore layers with interbanded vitreous quartzites and occasional phyllites.	2. Manganese-ore layers associated with bands of spessartite-quartz-rock and of vitreous quartzites.
3. A small thickness of jaspery quartzite.	3. A small thickness of jaspery quartzite, showing, on weathering, signs of schistosity ; not always present.
4. Schistose conglomeratic sericitic grit.	4. Schistose micaceous gneiss often containing pebbles of quartz, granites, and gneiss. This rock passes downwards into less schistose gneiss.

The gneiss underlying the manganese-ore band at Ukua would ordinarily get mapped as distinct from the Chilpis and as a part of the metamor-

[1] *Quar. Jour. Geol. Soc.*, LX, pp. 10-28, (1904).

phic and crystalline complex; in fact such has been the fate of this very occurrence at the hands of previous workers in this area. Yet the grit underlying the manganese-ore deposit at Bálághát must undoubtedly be regarded as a part of the Chilpi series. On the west side of the Wainganga the whole of the metamorphic and crystalline complex has been mapped as a single formation both by me and by Mr. Datta, except for the big range of quartzites running in a general south-westerly direction through Chandpur and Ámbagarh in the Bhandára district. But if time could be found for a detailed survey of this area, on maps of a large scale where such are available, it would be possible to distinguish a large number of outcrops as the highly metamorphosed equivalents of the Chilpis. The quartzites and mica-schists can probably be regarded as such and could easily be distinguished; but when it came to deciding which gneisses are to be regarded as metamorphosed sedimentaries or para-gneisses, and which are metamorphosed igneous rocks or orthogneisses, the work would have to be controlled and checked by a considerable amount of chemical analysis. That portions of this complex can fairly be regarded as the metamorphosed equivalents of the Chilpis is indicated by a very interesting microscopical feature of the mica-schists. On the low ground to the east of Sitasáongi Hill I collected a specimen of a very coarse-grained silvery mica-schist. Under the microscope the rock is seen to contain—besides muscovite, quartz, and a certain quantity of felspar—a number of tiny perfectly idiomorphic lavender-coloured tourmalines, a considerable quantity of ottrelite noticeable as green specks in the hand-specimen, and lastly an abundance of small idiomorphic crystals of composite character. They are partly opaque black, suggesting an iron-ore such as magnetite or ilmenite, and partly transparent yellow, corresponding in all respects to rutile.[1] Sometimes the boundaries between the iron-ore—which from its association with rutile is in all probability ilmenite—and the rutile are quite irregular; but more frequently the two minerals are arranged in bands, corresponding in all probability to twinning planes of the rutile; and the slide suggests that these composite grains were originally entirely rutile and

Mica-schists and phyllites of Bhandára and Bálághát.

[1] The presence of considerable amounts of titanium in the Sitasáongi, Bálághát, and Ukua schists and phyllites has been proved by Mr. T. R. Blyth.

that they have since been partly converted into ilmenite. An alternative view is that the structure is original and due to an intergrowth of these two minerals during the metamorphism of the sediments from which this rock was presumably derived, their arrangement being determined by the strong tendency to twinning possessed by rutile. This rock was collected in a region where all the rocks are so highly metamorphosed that one would not at first suspect the presence of the Chilpis. The interest and importance of this rock lies in the fact that the phyllites occupying the ridge immediately to the west of the Bálághát ore-ridge are found, although usually much less coarsely crystalline, to show exactly the same minerals as the Sitasáongi rock: so that it would often be impossible to separate the slides prepared from the rocks of the two localities once they had become mixed. This extraordinary likeness extends even to the structure of the complex rutile-ilmenite grains. In this neighbourhood there is, of course, no doubt that these phyllites belong to the Chilpi-Ghát series. Hence there can be little doubt that the Sitasáongi rock also belongs to the Chilpi series, although it is in a more metamorphosed region than at Bálághát. But it must not be supposed that all the Chilpi phyllites and mica-schists are petrologically precisely the same as the rock described above. Thus, of some specimens of mica-schist collected from the Chilpi area near Ukua, one specimen shows the tourmaline and ottrelite, but not the composite rutile-ilmenite grains. Instead of the latter it contains scattered grains of a black iron-ore round each of which there is a beautiful halo of red hematite. Whilst another specimen from the same locality contains, in addition to the usual constituents, sphene and colourless garnet(?). Similar interesting comparisons could easily be made between other rocks of the Chilpis and metamorphic and crystalline series, respectively, but none of them are so striking as the example given above.

The 'country' of the gondite series.

When one comes to examine the 'country' of the gondite series it at once becomes evident that the rocks most closely associated with the manganese-bearing rocks and ores are mica-schists, quartzites, and more rarely schistose gneisses, which are usually very siliceous. Rarely, in fact practically never, are the rocks of the gondite series closely associated with hornblende-schists, crystalline limestones (I am referring here, of course, to the manganese bearing rocks free from piedmontite), or gneisses of igneous origin. This

one would not expect were the gondite rocks of igneous origin as there is no apparent reason why they should always have chosen rocks of original sedimentary origin into which to intrude themselves. For the quartzites and para-gneisses are not any less strong structurally than the hornblende-schists, ortho-gneisses and crystalline limestones. Moreover, why should the manganese-bearing rocks associated with the crystalline limestones almost invariably contain piedmontite, with spessartite and rhodonite as a rule absent, or only present in small quantity; whilst the manganese bearing rocks associated with the mica-schists, quartzites, and para-gneisses, are characterized by the almost invariable absence of piedmontite and the frequent great abundance of spessartite and rhodonite? The only explanation that seems to meet the case is that the manganese-bearing rocks were deposited as sediments with the rocks with which they are associated, so that they partake to a certain extent of the chemical composition of the enclosing rocks.

Main conclusions as to origin.

The conclusions that it seems legitimate to draw from the preceding paragraphs are:—

(1) That the portions of the metamorphic and crystalline complex with which the manganese-bearing rocks of the gondite series are associated in the districts of Chhindwára, Nágpur, Bhandára, and Bálághát, are the more highly metamorphosed equivalents of the rocks that have been designated the Chilpi Ghát series in the Bálághát district.

(2) That the manganese-bearing rocks are not intrusive in these metamorphosed sediments, but have been formed by the metamorphism of manganese-bearing sediments deposited contemporaneously with the sands, clays and impure grits, from which these quartzites, mica-schists, and gneisses, have been formed.

It should be noticed that there is nothing in the mineral composition of the rocks and ores of the gondite series that seems in the least repugnant to this theory that they are metamorphosed sediments.

The shape of the areas of deposition.

The question naturally arises as to the shape of the masses of water in which the manganiferous sediments were deposited. A reference to the map (Plate 43) of this area will show what a large number of outcrops of the rocks and ores of the gondite series have been found. It will also be seen that the form these outcrops assume is that of long bands. In a few cases these bands can be traced until they die out in lenticular fashion. As good

examples may be cited the Gaimukh deposit (fig. 47, p. 782) in the Chhindwára district, the Kándri deposit (Plate 32) in Nágpur, and the Bálághát deposit. Of these the Gaimukh deposit terminates thus at both ends, the Kándri deposit at the south-east end in South Hill and the Bálághát deposit at its northern end. But in the majority of cases the termination of the deposit in either direction is hidden by soil or jungle, and as these deposits are often arranged in strings so that the strike of one if produced would carry it into another a mile or two away in the direction of the strike, it is not possible to say if this lenticular thinning out is the rule or not. One would suspect that in many cases the ore-band is continuous between many of the so-called separate deposits and that it only needs the uncovering of the intervening ground, no doubt in many cases to a considerable depth, to demonstrate this continuity. An example is the string of deposits in the Nágpur district stretching in an average west to east direction from Dumri Kalán on the west, through Sátak, Beldongri, Nandapuri, Lohdongri, Kácharwáhi, and Waregáon, to Khandála on the extreme east. All these deposits, except Khandála, are situated in the alluvium, and very little or no rock is to be seen in the ground between the separate deposits, everything being obscured by alluvium.

The number of ore-horizons.

The mere fact that the majority of the deposits lie along fairly well defined lines would at first sight be taken as indicating that they correspond to one bed or horizon that has been folded, so that its edges have come to the surface along several more or less linear outcrops. And the fact that the deposits known to occur in the portions of the Chilpis that are only moderately metamorphosed, lie at a horizon that may be regarded as being near the base of this series, might be taken to indicate that the manganese-ore deposits correspond to a definite horizon near the base of the Chilpis, the conglomeratic grit underlying the manganese-ore horizon at Bálághát being possibly the base of this formation. The truth of such a hypothesis cannot at present be either proved or disproved; it would need a very close piece of work, involving the very careful correlation of the various beds of rock, in both the Chilpi and crystalline areas, to settle the question. The mere fact that there are apparently several parallel bands of deposits in the crystalline portion of the Nágpur-Bálághát area might be thought to be opposed to the idea that there is only one ore-horizon in this area. It must be remembered, however, that the deposits situated in the more metamorphosed areas owe their more crystalline character to the fact that the more

deeply buried portions of the folds into which the Chilpis were thrown at the end of the period of sedimentation have here been exposed by the denuding agencies of nature. Were two horizontal sections to be constructed across a series of folded beds of rock at two levels, the one nearer the surface might only cut a certain bed, such as a layer of manganese-ore for example, twice, namely, on the two outer edges of the fold. But at a lower level towards the base of the main trough formed by the fold, the simple fold would probably be complicated by a series of minor folds. This crinkling of the base of the trough would cause a line of section near the base to cut the ore-layer several times. Thus in figure 21, a

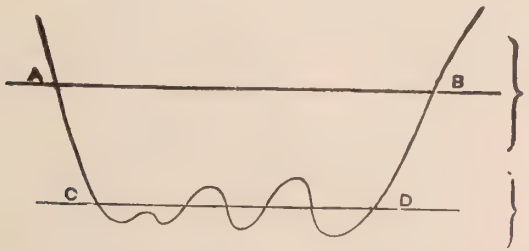


Fig. 21.—Ideal section across a syncline of manganiferous rock.

section at the level AB would only cut the ore-layer in two places, namely, A and B, and the manganese-ore body would be of the less metamorphosed type like that of Bálághát. But a section at the level CD would cut the ore-layer several times, in the figure 6 times, and the ore-layer would be of the highly metamorphosed type like those of the metamorphic and crystalline complex[1]. From this it is evident that the fact that there are several roughly parallel *ore-bands* in the more metamorphosed portions of the Archæan complex of this area does not conflict with what would be expected if there were only one *ore-horizon*. This does not, however, obviate the fact that the existence of several ore-outcrops could also be explained by the actual existence of several ore-horizons. I do not here give a definite expression of opinion one way or the other, except to say that it certainly seems more probable that the repetition of the ore-bands in the more metamorphosed parts of this area is due to the bringing of a

[1] Rocks that were only buried to the depth represented by the line AB possibly did not get below Van Hise's upper zone of katamorphism; whilst rocks that reached the depth represented by the line CD probably entered Van Hise's lower zone of anamorphism.

fewer number of ore-bands to the surface than the total number of lines of outcrop, especially in view of the fact that only one ore-horizon has been yet discovered in the true Chilpi area[1].

Admitting, then, that the outcrops of manganese-bearing rocks and ores correspond to only a small number of original beds of ore, the question again arises as to whether the deposition of ore over a particular horizon was continuous, *i.e.*, whether the manganese oxides were laid down as a continuous sheet; or whether they were deposited in a patchy fashion, such as would be the case were the deposition taking place in a series of basin-like areas, such as a series of lagoons or lakes. At first sight it would seem evident owing to the discontinuity of the ore-bodies situated along one line of outcrop that the latter theory is the correct one. But as explained above, this interruption in the continuity of one particular outcrop may only be apparent and due to the obscuring of the intervening ground. In some cases, however, it is real, namely those in which there can be no doubt that the ore deposit is of lenticular shape and definitely dies out in lenticular fashion in a comparatively short distance. This interruption might, of course, be explained as due to the squeezing out of a previously continuous bed into separate lenticular portions under the influence of the severe tectonic disturbances to which these rocks were subjected. Fortunately, however, one of these cases of lenticular thinning out occurs at Bálághát, where the degree of metamorphism to which the ore-layer has been subjected could not be regarded as in any way adequate to account for such a squeezing out. It thus seems as if we can say with some degree of certainty that these manganiferous sediments were partly deposited in circumscribed areas of the nature of lagoons or lakes and that they were partly deposited in areas of considerable extent such as a comparatively large lake.[2]

Deposition took place in lagoon- or lake-like areas.

One feature that is worth noting is that the ending of some of these areas is very sudden. Thus the south-east end of the ore-band in South Hill at Kándri, as seen in level No. 1, is about 70 feet across, and in the course of a few yards the band is rounded off and suddenly disappears beneath the surface. If this be a deposit that was originally laid down in a basin having this shape before it was subjected to the tectonic movements characterizing the termination of the Dhárwár period of sedimentation,

Some ore-lenticles due to squeezing and some to deposition in basin-shaped areas.

[1] See the account of the Thirori deposit, page 699.

[2] I am discussing in this place the Nágpur-Bálághát area only; there is of course little doubt that the ores deposited in Dhárwár times in other parts of India, such as Jhábua and Nárukot, were deposited in separate areas of deposition.

then the shape of the original basin must have been a somewhat curious one, with very steep banks. This might mean that the basin was one abutting against a hill remaining from the pre-Dhárwár land surface ; but it more probably means that the shape of the original basin has been distorted by the earth movements to which it has been subjected. Another example of this very rapid thinning out of the manganese ore band is the Gaimukh deposit, a rough sketch of which is given on page 782. If we explain this sudden thinning out of certain deposits in the way suggested above, namely as due to distortion during tectonic movements, then it is difficult to avoid the supposition that in at least a few cases the pressure has been sufficient to squeeze out the ore-bands into separate lenticles. The formation of a few separate lenticles in this way is not to be taken as negativing the explanation given above of the shape of the bodies of water in which the manganese-ores were laid down, but rather as modifying that explanation slightly.

Prospecting for manganese-ore at the base of the Chilpis.

It is obvious that if it be the case that there is a manganese-ore horizon situate near the base of the Chilpi series, it ought to be possible to make use of this fact, and in fact to test it, by carefully prospecting along the lines that are marked in the map of this area (Plate 43) as bounding the Chilpi series from the remainder of the Archæan complex. The region especially favourable for this purpose is, of course, the southern portion of the Bálághát district and the adjoining parts of the Bhandára district.

The Gondite Series in Jhábua.

The occurrence of the rocks of the gondite series that I was able to examine at Kájlidongri in Jhábua State, Central India, and which, as has already been noticed on page 283, is enclosed in rocks that are to be regarded as a southern extension of Arávalli system of Rájputána, is very similar to the occurrences of this series in the Central Provinces. It is folded up with rocks that may variously be called phyllites or mica-schists, according to the stage of re-crystallization they have reached. The ore-body itself consists of layers of manganese-ore interbanded with red vitreous quartzites identical in all respects with the red quartzites that occur in the ore-body at Bálághát. This red quartzite is very fine-grained and is seen under the microscope to owe its colour to clouds of minutely divided red dust collected in clouds in the interiors of the grains of quartz. These clouds are usually centrally disposed in their respective

quartz grains and doubtless consist of ferric oxide. The absolute identity of the quartzites from these two widely distant manganese-ore deposits is eloquent testimony to their having been formed under the same conditions, and is about as good a proof of the identity of the Chilpi Ghát and Arávalli series as could well be found; provided that the continuity of the supposed Arávalli rocks of Jhábua with the typical Arávallis of Rájputána be once proved, as no doubt it will be one day. In respect to the degree of metamorphism that the 'country' and the interbanded quartzite layers of this deposit have suffered, this deposit may be regarded as the equivalent of the Bálághát deposit of the Central Provinces. It has, however, been considerably more metamorphosed, as is shown by the presence of spessartite and rhodonite in various parts of the deposit and by the fact that there is a considerable amount of braunite present. In this deposit, moreover, the manganiferous amphibole and pyroxene, winchite and blanfordite, respectively, have been developed; as well as a crimson manganiferous mica. Further, the manganese-epidote, piedmontite, has also been formed in the 'country' of this deposit; this being the only occurrence of piedmontite that has yet been found in India outside the crystalline limestones, with the exception of the occurrence at Jothvád noted in the next section.

The Gondite Series in Nárukot.

One occurrence of the rocks of the gondite series has also been found at Jothvád in the Nárukot State, Rewa Kántha Agency, Bombay Presidency. This occurrence is associated with rocks which have reached at least the same degree of metamorphism as those characterizing the rocks of the metamorphic and crystalline complex of the Central Provinces. The whole series of rocks has been intensely folded, and intruded by a porphyritic biotite granite, which from its mineralogical and petrographical characters may be regarded as the equivalent of the Bundelkhand granite of Central India. Apophyses are seen to start from this granite and penetrate the series of banded and folded rocks constituting the main mass of the hill in which the manganese-bearing rocks occur, and in these apophyses or granite veins various interesting minerals, characterized by the presence of a certain quantity of manganese, taken up no doubt from the manganese-bearing rocks at the time of their injection into the gneissic series, have crystallized out. The most interesting feature of the occurrence lies, however, in the fact that in one spot, namely at the junction of the main mass of the granite with the gneissic series, the

granite contains inclusions of various of the rocks of the gneisses series (see Plate 17). Amongst the rocks so included are some of the manganiferous varieties, both manganese-silicate-rocks and crystalline manganese-ores. In some cases these ores seem to have been formed by the alteration of the manganese silicates; but in the majority of cases they were formed at the time of the metamorphism of the manganiferous sediments, by the compression of the manganese oxides, with absorption of the small amount of silica required for the formation of braunite in accordance with the equation given on page 290. In so far as any portions of the ore found in these masses of rock included in granite can be clearly distinguished as having been formed by the alteration of the manganese silicates, they may be regarded as evidence that the formation of the manganese-ores from manganese-bearing silicates took place before the intrusion of this granite, that is in all probability in Archæan times. And as the manganese-bearing rocks of this hill are sufficiently like those of the Central Provinces to justify the supposition that they were formed at the same time and under similar circumstances, it seems justifiable to extend this piece of information to the rocks of the Central Provinces and suppose that there also at least a portion of the alteration of manganese silicates into manganese-ore took place in Archæan times.

Alteration of manganese silicate to manganese-ores took place in Archæan times.

Although the rocks of this hill are many of them very similar to those occurring in the gondite series in the Central Provinces, yet they are somewhat different owing to the frequent presence of apatite in considerable abundance. A reference to the description of this occurrence of manganese-bearing rocks on page 330 will show the great variety of these rocks, containing as they do the following manganiferous minerals:—spessartite, rhodonite (?), piedmontite, manganese-mica, manganiferous pyroxene showing the blanfordite type of pleochroism, and another pyroxene also probably containing manganese. Since some of these manganiferous rocks contain felspars, a rather unusual mineral in the gondite series, it is evident that, if the rocks were formed from sediments, these sediments must have been, in at least some cases, felspathic. Also, from the fact that some of the manganese-bearing rocks contain calcite, it is evident that the sediments were often calcareous. The other constituents point to the presence of quartz and clay in the original sediments. The various banded rocks associated with the manganese-bearing rocks are also of somewhat unusual character, and if they were formed by

the metamorphism of sediments, as they must have been if these rocks are to be correlated with the rocks of the Central Provinces, these sediments must have been more impure and more varied than usual. The chalcopyrite found in one of them must have been subsequently introduced.

CHAPTER XVI.

GEOLOGY—*continued.*

The Gondite Series—*continued.*

Mineralogy—Petrology—Nomenclature—Structure—Lists of rocks—Descriptions of rocks—List of localities—Areas to prospect.

Mineralogy of the Gondite Series.

The following minerals have been found in the rocks and ore-bodies of the gondite series of the Central Provinces, Jhábua, and Nárukot :—

List of minerals found in the rocks and ore-bodies of the gondite series.

Albite
Amphiboles
Apatite
Arsenates
Barytes
Beldongrite
Blanfordite
Braunite
Calcite
Chalcedony
Halite.
Hematite
Hollandite
Limonite
Magnetite
Manganese-amphiboles
Manganchlorite ?
Manganesian phosphate
Manganmagnetite
Manganese-micas
Manganese-pyroxenes
Microcline
Oligoclase
Orthoclase
Opal
Piedmontite
Plagioclase
Psilomelane
Pyrolusite
Pyrophanite(?)
Pyroxene (pale green)
Quartz
Rhodochrosite
Rhodonite
Rutile
Scapolite
Sitaparite
Spessartite
Sphene (?)
Talc
Tremolite
Vredenburgite
Winchite
Wollastonite

In veins traversing the rocks and ores of this series the following minerals have been found :—

List of minerals found in veins piercing the rocks and ores of the gondite series.

Arsenate of Mg., etc. (Kájlidongri).
Barytes (Kájlidongri).
Hematite.
Limonite (Kodegáon).
Psilomelane.
Pyrite (Kodegáon).
Quartz.
Hollandite (Kájlidongri).

In granitic, pegmatitic and felspathic intrusions, usually in the form of veins, piercing the rocks of the gondite series the following minerals have been observed :—

List of minerals found in rocks intrusive in the gondite series.

Albite.
Amphibole (lilac).
Apatite.
Biotite.
Blanfordite (Jothvád, Rámdongri, and Kác
Braunite (Kácharwáhi and Sátak).
Carpholite ?
Greenovite (Jothvád).
Juddite (Kácharwáhi).
Manganese-garnets.
Microcline.
Microperthite.
Oligoclase.
Orthoclase.
Plagioclase.
Pyroxene (brown) (Kusumbah).
Quartz.
Sphene.
Tourmaline.
Zircon.

As will be seen from the lists given above, many of the minerals in both the intrusives and the mineral veins are characterized by the presence of either small or large quantities of manganese, which often impart to the mineral its distinctive properties. This manganese has, no doubt, been obtained from the rocks of the gondite series through which the molten rocks or heated waters, as the case may be, have passed. It is not known whether one of the rocks, namely one composed of quartz, carpholite (?), and oligoclase-albite, is an intrusive or a mineral vein. From the fact of the presence of felspar it might be thought to be obviously an intrusive. But it is now well recognized that felspars are not infrequently formed in true mineral veins. It has, however, been considered here as an intrusive.

In the first list given above only those minerals are mentioned that are found right in the masses of manganese-silicate-rock or in the actual peripheral zone of the deposit. In Dhárwár times the sediments deposited both before and after the manganiferous sediments proper must often have contained small quantities of manganese ; so that when the rocks were metamorphosed some of the rocks thus produced often contained small quantities of manganese-bearing minerals, without in any way forming part of the ore-body. Such slightly manganiferous sediments tend, of course, to occur close to the manganiferous rocks and ores, because the change from the conditions under which non-manganiferous sediments

were deposited to those under which the manganese-oxide sediments were laid down cannot have been quite sudden. Amongst the minerals containing manganese that occur in the 'country' of the deposit as distinct from the deposits themselves, are the following :—manganese-garnet, manganmagnetite, and ottrelite; whilst psilomelane and pyrolusite are often formed in the 'country' by secondary infiltration of manganese-bearing solutions from the ore-body. The following is a full list of the minerals recognised in the 'country' of the masses of manganese-silicate rock and manganese-ore :—

List of minerals found in the rocks forming the 'country' of the manganese-ore deposits.

Apatite	Muscovite
Biotite	Ottrelite
Braunite(?)	Piedmontite
Calcite	Plagioclase
Chalcopyrite	Psilomelane
Chlorite	Pyrolusite
Diopside	Quartz
Enstatite(?)	Rutile
Epidote	Sapphirine
Garnet	Scapolite
Hematite	Sericite
Hornblende	Spessartite
Ilmenite	Sphene
Magnetite	Talc
Manganmagnetite	Tourmaline
Martite	Wollastonite
Microcline	Zircon

Petrology of the Gondite Series.

Nomenclature of the gondite series.

We can now deal with the question of the nomenclature of the rocks of the gondite series. The type rock is one composed practically entirely of a manganese-bearing garnet approximating in composition to spessartite, and of quartz. The garnet occurs as a large number of tiny round grains set in a matrix of mosaic quartz, the grains of which are usually of about the same size as the garnet grains. The rock appears to the unaided eye as a very fine-grained rock of which the structure just seems visible. The characters of this rock will be given in more detail later. This is, however, the rock to which it is proposed to give the name *gondite*. Similar rocks have probably been found in the metamorphic rocks of other parts of the world, *e.g.* in Texas [1]; but I am not aware that any name has ever been given to such rocks. Probably they have not previously been found in

[1] Penrose, *An. Rep. Geol. Surv. Arkansas* for 1890, Vol. I, Chap. XVI.

sufficient quantity for the need for such a term to be felt. The nearest rock to gondite seems at first sight, on account of the spessartite present, to be that to which the name *queluzite* has been given by Dr. Orville Derby; but, as will be judged from page 274, this rock is really considerably different to gondite, and more closely related to kodurite, one of the chief points being that it is supposed to be of igneous origin. To varieties of the spessartite-quartz-rocks of coarser grain the name gondite may also be extended, but such rock is not to be regarded as the typical rock. Under this extended meaning of the term some varieties of gondite will possess quite a coarse-grained structure, the garnets sometimes being as large as an inch in diameter. Very often the manganese-silicate rock consists entirely of garnet, the quartz being absent. It will then be known as *spessartite-rock*. When the rock contains important quantities of apatite, as at Jothvád in Nárukot, the rock is an *apatite-gondite*. Spessartite-quartz-rock containing rhodonite is *rhodonite-gondite*. It is not proposed to introduce any special name for the rocks rich in rhodonite, because rhodonite is a much less common mineral than spessartite in the rocks of this series. The rock found at many localities, composed entirely of rhodonite, will therefore be known as *rhodonite-rock*. There may be a small quantity of manganese-garnet present, which may increase in quantity until it predominates over the rhodonite. The rock then becomes *rhodonite-spessartite-rock or rhodonite-gondite*, according as quartz is absent or present. Sometimes the rock contains a brownish to greyish radiate fibrous mineral that is probably an amphibole. Such a rock would be termed an *amphibole-gondite*. Occasionally scales of a manganiferous mica may be present in the spessartite-quartz-rock. The rock is then a *mica-gondite*. The other rarer rocks found in this series, such as the garnet-rhodonite rock containing barytes and a manganesian phosphate, found at Chargáon, Nágpur district, will be known by the names of their constituents. There are many other varieties of rocks in this series; but it is not necessary to explain the meaning of their names as given in the complete list on page 329; they are self-evident after the foregoing explanation.

Structure of the bodies of manganese-bearing rocks.

Before proceeding to give a brief account of the petrology of the rocks of the gondite series, it will be necessary to give a short account of the structure of the bodies of ore and manganese-bearing rocks. Except when the ore-bodies are composed entirely, or practically so, of manganese-ore, they usually exhibit a banded structure due to the alternation of layers of

different composition. Some of these layers, and in many cases nearly all of them, consist of rocks containing a high percentage of manganese, and are consequently largely composed of manganese-bearing minerals. The typical rocks in these manganiferous bands are gondite, spessartite-rock, rhodonite-gondite, rhodonite-spessartite-rock, and rhodonite-rock, and the manganese-ores, either original or formed by the alteration of the manganese-silicate-rocks mentioned above. As partings to these manganiferous layers are various rocks that either contain only a small amount of manganese or are practically free from this element. The commonest of these parting layers are quartzites of various colours and texture, their characters depending to a large extent on the nature of the impurities that the sands from which they were formed contained before they suffered metamorphism. Thus the quartzite may be red from the presence of ferric oxide, black from the presence of manganese-ores, or light grey or even white, owing to the comparative purity of the rock. Or again, the impurities may have crystallized out as definite minerals giving rise to pyroxenic quartzites, spessartiferous quartzites, and so on. In other cases the impurities have given rise to various mica-quartz-schists and mica-schists, in which the mica often shows unusual types of pleochroism owing to the presence of small quantities of manganese. Again at the periphery of many of the masses of manganiferous rocks various interesting rocks are often found that have either been formed by an interaction with the manganiferous sediments, or have been produced by the metamorphism of sediments that contained considerable quantities of manganese, but not enough to make the rock a portion of the ore-body. Such rocks often contain manganiferous pyroxenes, garnets, micas, and amphiboles.

In the ore-body the rocks are, as has been mentioned above, usually arranged in bands. These bands are often of quite small thickness. Thus a rock may consist of layers of gondite and quartz, only $\frac{1}{2}$ an inch to an inch thick; or one layer of gondite or of rhodonite-rock may be as much as 1, 2, or even 3, feet thick. On the outcrop, these banded rocks, if they have not been largely altered with formation of manganese-ore, often show differential weathering. Thus a layer of quartz may stand up leaving the alternating layers of gondite occupying slight depressions.

Owing to their mode of formation, namely by the metamorphism of sediments, the masses of manganese-bearing rocks and ores naturally appear to be definitely bedded, although, owing to the fact that these sediments were deposited in basin-like areas, or because they have been

subsequently squeezed out, they tend to change in thickness along the strike, with an ultimate thinning out of the mass of rock. Moreover, as one would expect in the case of rocks that have been subjected to great tectonic influences, these beds of rock are often folded so as to cause a duplication at the surface of the outcropping bands of rock. In some cases, such as at Mánegáon (page 944), this fact of two outcropping beds of ore joining together below the surface has been definitely proved by the work carried out in the opening up of the deposit. In others it is to be inferred. Thus at the time of my visit in 1904 to Thirori there were apparently five distinct outcropping bands of ore. I am told that subsequent work at this place has shown that a part of this multiplicity of ore-bands is due to the folding of one bed of ore. One cannot say, of course, if all the cases of two or more parallel ore-bands are due to the folding of a single bed of ore. There is no *à priori* reason why there should not be at any one place two or more parallel beds of ore or manganese-silicate-rock.

Dip of the bands of the gondite series.

Owing to the fact that these beds of ore and manganese-silicate-rock have been folded, they are usually found to dip at steep or moderately steep angles, although a small dip is also sometimes encountered, especially at the summit of an anticlinal fold, as at Panchála; or as at Pachára, where the whole bed of ore seems to be nearly horizontal.

Dimensions of the masses and bands of the gondite series.

The masses of manganese-bearing rocks and ores often attain great dimensions. Thus the Bálághát deposit is $1\frac{3}{4}$ miles long; at Mánegáon the ore-body is $1\frac{1}{2}$ miles long; the ore-band running from Ghondi through Gudma and Ukua to Samnapur must be at least 4 miles long; whilst at Thirori the ore-bands can be traced for about 6 miles. If, however, any of the lines of deposits represent a continuous run of manganiferous rock beneath the surface then the ore-band must be in some places at least 10 miles long, as for example in the continuation of the Thirori ore-band towards the north-east through Chaukhandi and Chikmára. In breadth the bands of the gondite series and associated ores may be of very small thickness, such as 2 or 3 feet as at Wagora. Or they may be of great breadth. Thus the true thickness of the ore-band at Mansar is about 50 feet at its thickest portion, where it in some places consists almost entirely of ore, whilst at Rámdongri the lenticular mass of ore and spessartite-bearing rock measures about 1,500 feet across at its greatest width. This enormous thickness may, however, be due to the compression together of two or more folds of the manganese-bearing rocks, although there is no evidence to show that such is the case.

Lists of Rocks.

Space will not permit me to give in this Memoir a detailed account of the petrological characters of these rocks; so that I propose to first give a classification of the various rocks that have so far been found in these masses of manganese-bearing rocks and ores, and then to give short petrological accounts of the commonest and most characteristic varieties.

The following list gives a classification of the rocks found up to the present in the gondite series. From this list, however, the rocks containing manganese-ores have been omitted, because it is impossible to decide which of them are to be regarded as the direct product of the metamorphism of the original manganiferous sediments and which have been produced by the chemical alteration of the manganese-silicate-rocks. The parting layers of quartzites and micaceous schists separating the layers of manganese-silicate-rock have also been omitted from this classification, because they will be given in a separate list later on.

List of the rocks found in the gondite series as represented in the Central Provinces.

With quartz.	Without quartz.
Gondite	*Spessartite-rock*
Rhodonite-gondite	*Rhodonite-spessartite-rock*
Apatite-gondite	Apatite-spessartite-rock
Amphibole-gondite	Amphibole-spessartite-rock
Amphibole-rhodonite-gondite	Amphibole-spessartite-rhodonite-rock
Amphibole-apatite-gondite	. . .
Magnetite-gondite	Magnetite-spessartite-rock
Rhodochrosite-gondite	. . .
. . .	Rhodochrosite-spessartite-rhodonite rock
. . .	Rhodochrosite-rhodonite-rock
Orthoclase-gondite	Spessartite-orthoclase-rock
Microcline-gondite	. .
Pyroxene (brown)-microcline-gondite	. . .
. . .	Apatite-felspar-spessartite-rock with mica
Orthoclase-amphibole-rhodonite-gondite with rhodochrosite (?)	. . .
Rhodonite-quartz-rock	*Rhodonite-rock*
. . .	Rhodonite-rock with magnetite, spessartite, and manganese-mica
. . .	Barytes-spessartite-rhodonite rock
. . .	Barytes-spessartite-rhodonite-rock with a manganesian phosphate

Owing no doubt to the fact that practically only one occurrence of the gondite series has been examined in each of the other two areas where this series has been found, many of the rocks found in the gondite series as represented in the Central Provinces have not been found in Jhábua or Nárukot. Whilst, owing probably to original differences in the composition of the sediments deposited in these two areas, many rocks are found in them that have not been found in the gondite series as represented in the Central Provinces. In the Central Provinces the calcareous manganese-bearing sediments that gave rise to the piedmontite-limestones were deposited separately from the practically non-calcareous sediments from which the typical gondites were produced ; whilst in Nárukot the calcareous and non-calcareous manganiferous sediments were deposited in alternating layers, so that, now that they have been metamorphosed, the typical rocks of the gondite series are found associated with rocks that it is necessary to consider as a part of this series, but which are to be regarded as an abnormal development of the series. In the same way in Jhábua, as represented by the one deposit at Kájlidongri, the original manganese-bearing sediments must have been largely of the type that gave rise to the typical rocks of the gondite series of the Central Provinces with occasional layers of more calcareous nature. The following is a list of the rocks of the gondite series as represented in the Kájlidongri deposit in Jhábua State :—

List of the rocks found in the gondite series as represented in Jhábua.

Gondite
Spessartite-rock.
Apatite-gondite.
Apatite-spessartite-rhodonite-rock.
Rhodonite-apatite-quartz-pyroxene(yellow)-rock with some spessartite
Quartz-plagioclase-spessartite-piedmontite-rock.
Braunite-spessartite-quartz-arsenate-rock.
Amphibole-pyroxene (yellow)-quartz-rock

Whilst the following list shows the rocks found in this series as represented in Nárukot State, Bombay :—

List of the rocks of the gondite series as represented in Nárukot.

Gondite.
Apatite-gondite
Piedmontite-apatite-gondite with a little pyroxene.
Piedmontite-apatite-spessartite-rock.
Pyroxene (yellow)-apatite-gondite.
Calcite-gondite with pyroxene, apatite, and wollastonite.
Rhodonite(?)-pyroxene(yellow)-gondite.
Calcite-rhodonite(?)-pyroxene(yellow)-gondite.
Pyroxene(yellowish)-gondite with calcite
Calcite-gondite with pyroxene, apatite, and wollastonite.
Wollastonite-apatite-calcite-gondite (or crystalline limestone).
Piedmontite-wollastonite-apatite-calcite-gondite.

Rocks of the gondite series containing braunite.

As has been mentioned on a previous page (294), although it is thought that a considerable proportion of the manganese-ores associated with the rocks of the gondite series has been derived from these rocks by their chemical alteration, yet a considerable proportion of the ores has been in all probability formed direct from the original manganiferous sediments, whenever they were deposited practically free from admixture with other sediments, such as sand or clay. It is now not possible to determine what proportion of the ores have been formed in these two ways. Consequently in the lists, given above, of the rocks of the gondite series, the members containing original manganese-ores have not been included. The lists might therefore be considerably extended by adding many varieties containing braunite; but it would not be certain that all these rocks were the direct products of the metamorphism of original sediments. Thus some of the rocks composed of braunite and spessartite may be the original products of metamorphism, whilst others may have been originally composed entirely of spessartite and owe their braunite to subsequent chemical changes. In the case of the gondite series in the Central Provinces the varieties containing original braunite are more likely to be those that can be formed by adding this mineral to the rocks given in the right-hand column on page 329, *i.e.* to those free from quartz, than those formed by adding it to the rocks shown in the left-hand column, *i.e.* to those containing quartz. For in the latter case the tendency during metamorphism would have been for the constituents that might have given rise to braunite to combine with a further quantity of quartz with the production of rhodonite. Thus, on account of the possibility of the reaction expressed by the following equation, one would expect any braunite, if formed, to pass in the presence of free silica into rhodonite:—

$$\underset{\text{Braunite}}{3Mn_2O_3.MnSiO_3} + \underset{\text{Quartz}}{6SiO_2} = \underset{\text{Rhodonite.}}{7MnSiO_3} + 3O.$$

If, however, during the metamorphism of the manganiferous sediments some braunite were formed and enclosed in spessartite or rhodonite, it might be preserved; so that one would expect to find some cases of rocks containing both quartz and braunite, if only the braunite were enclosed in another mineral, such as spessartite, which would protect it from the quartz. Such cases are frequently found. Moreover, it sometimes happens that these manganiferous rocks contain these two minerals in direct contact in such a way that they must have been originally formed in this position at the time of the metamorphism of the original sediments. A

case in point is the winchite-braunite-calcite-quartz-rock or winchite-schist of Kájlidongri, in which the braunite grains are idiomorphic in shape, taking the form of tiny octahedra, which are enclosed in all the other minerals in such a way that there can be no doubt that they were formed at the time of formation of the schist by the metamorphism of the sediments from which they were derived.

As has already been mentioned, the rocks of the gondite series, *i.e.* those enumerated above, occur interbanded both one with another and with various quartzites and micaceous schists, many of which differ from ordinary quartzites and schists on account of their manganese contents. The following is a list of the rocks occurring interbanded with the manganese-silicate rocks and manganese-ores of the Central Provinces :—

List of the rocks interbanded with the rocks of the gondite series in the Central Provinces.

Quartz-rock.
White quartzite.
Light grey quartzite.
Dark grey quartzite.
Black quartzite.
Red quartzite.
Purplish quartzite.
Pinkish quartzite.
Pyroxenic quartzite.
Spessartiferous quartzite.
Quartzites containing manganese-ores
Micaceous quartzite.
Quartz-schist.
Fine-grained mica-quartz-schist.
Biotite-quartz-schist.
Muscovite-schist.
Manganiferous micaceous schists.
Manganiferous gneiss.

As we have only one deposit of any importance in Jhábua to deal with the list of rocks interbanded with the rocks of the gondite series there is naturally a smaller one than for the Central Provinces. It is as follows :—

List of the rocks interbanded with the rocks of the gondite series in Jhábua.

Light grey, dark grey, black, red, and pinkish, quartzites.
Pyroxenic quartzite.
Spessartiferous quartzite.
Manganiferous, micaceous, and pyroxenic, schists.

In Nárukot at the one known occurrence of rocks of the gondite series the interbanded rocks are considerably different to those of the Central Provinces and Jhábua. The following is a list :—

List of rocks interbanded with the rocks of the gondite series in Nárukot.

Quartz-rock.
Red quartzite.
Pyroxenic quartzite.
Quartzite containing manganese-ores.
Manganiferous micaceous schists.

Whilst intimately associated with these are rocks composed of the following minerals :—Quartz, garnet, pyroxene, epidote, hornblende, plagioclase, microcline, biotite, wollastonite, sphene, apatite, calcite, tourmaline, with in one case, chalcopyrite. The rocks composed of these minerals take the form of banded gneisses.

Amongst the rocks given above as occurring interbanded with the rocks of the gondite series are in all three areas 'manganiferous micaceous schists'. These rocks are often of very complex composition owing to the great variety of minerals they contain. The following is a more detailed list of these rocks :—

List of the manganiferous micaceous schists found associated with the rocks of the gondite series.

In the Central Provinces :—Only known to occur to any extent at one locality Kácharwáhi. These have not yet been examined.

In Jhábua :—Found at Kájlidongri. Apart from the rocks containing the blue amphibole, winchite, and of which a list will be given below, the following rocks can be included in this group, talc sometimes taking the place of the mica :—

Mica(yellow)-rock.
Apatite-talc(?)-felspar-quartz-rock.
Mica(crimson)-amphibole-apatite-talc-rock.
Apatite-mica(orange)-blanfordite-quartzite.

In Nárukot :—Found at Jothvád. The manganiferous micaceous schists are such as, from their outward physical aspect, one would designate 'biotitic sandstones' in the field. The following is a list :—

Schistose banded rock containing the following minerals in one band :—apatite, microcline, plagioclase, quartz, manganese-ore (probably original), mica (showing pleochroism in pink, green, and orange), and a little of a blue pyroxene ; with a second band formed of quartz, apatite, manganese-ore, and pyroxene, pleochroic in pink and bluish green.

Schistose rock composed of apatite, mica, microcline, quartz, manganese-ore, pyroxene (pink and green pleochroism), and an amphibole having the pleochroism of winchite.

Schistose rock, included in granite, containing quartz, microcline, apatite, spessartite, mica (orange brown), hematite plates, and a black ore.

At the Kájlidongri mine in Jhábua there is a series of rocks, associated with the manganese-ores, that is characterized by the presence of the lavender or blue amphibole to which the name winchite has been given (see page 149). These rocks have probably resulted from the metamorphism of a series of sediments characterized by the presence of large quantities of lime, magnesia, and manganese-oxides, in addition to the ordinary sand and clay. The minerals contained in the rock thus formed are the following:—Winchite, braunite, calcite, and quartz, with less frequently apatite, blanfordite, plagioclase, and crimson mica. Some 10 different combinations of these minerals have been found, but the most important are the following :—

List of winchite-bearing rocks.

Winchite-schist, composed of about equal proportions of winchite, braunite, calcite, and quartz.
Blanfordite-winchite-schist, composed of the foregoing minerals with blanfordite in addition.
Winchite-quartzite.
Blanfordite-winchite-quartzite.
Banded rock of winchite, blanfordite, braunite, felspar, quartz, apatite, calcite, and crimson mica.

As has been mentioned on a previous page, various interesting rocks are often found at the periphery of the masses of manganiferous rocks and are formed either by an interaction between the manganiferous sediments and the immediately under- or over-lying non-manganiferous sediments ; or, and more probably, by the direct metamorphism of these underlying or overlying sediments, which were not sufficiently manganiferous to give rise to rocks of the gondite series or to ores, but which yet contained sufficient manganese to give rise on metamorphism to unusual rocks. Of such rocks the following deserve notice :—

List of manganiferous rocks forming the 'country' of the gondite series.

Manganmagnetite-gneiss of Kándri and Mansar.
Spessartite-quartzite of Kándri and Mansar.
Manganiferous mica-schist containing a crimson mica (biaxial), a brown mica (uniaxial), and quartz, at Sítapathúr.
Hematite (manganiferous)-quartz rock at Ramrama.
Ottrelite-muscovite-schist at Sitasáongi and Bálághát.
Piedmontite-phyllite at Kájlidongri
Sandy-argillaceous rock containing winchite at Kájlidongri.

In addition to the rocks characterized by a notable proportion of manganese, there is a great variety of rocks forming the actual 'country'

of the manganese-ore bodies and bands of manganese-silicate-rock. The following is a list of such rocks found in the Central Provinces :—

List of the non-manganiferous rocks forming the 'country' of the gondite series in the Central Provinces.

Sericite-phyllite and schist.
Mica(muscovite)-schist.
Mica-quartz-schist.
Magnetite-mica-quartz-schist.
Biotite-schist.
Felspathic mica-schist.
Biotite-felspar-schist.
Talcose schist.
Schistose quartzite.
Felspathic schist.
Micaceous quartzite, often containing tourmaline.
Quartz-rock.
Quartzite.
Jaspery quartzite.
Hematite-quartzite.
Martite-quartzite.
Sapphirine(?)-enstatite-quartzite.
Conglomeratic gneiss.
Muscovite-gneiss.
Biotite-gneiss.
Hornblendic quartz-pyroxene-gneiss.
Calciphyre.
Crystalline limestone.
Tourmaline-quartz-rock.

This list should be compared with the list of minerals contained in these rocks given on page 325.

In Jhábua the actual 'country' of the two deposits visited consists :— at Kájlidongri of sericitoid phyllites usually separated from the ore-body by a small thickness of argillaceous-sandy rocks : and at Rambhapur of siliceous crystalline limestone.

In Nárukot, at the single occurrence of the rocks of the gondite series, the actual 'country' of the manganiferous rocks consists of the banded gneisses, mentioned on page 333, with which they are so intimately associated : whilst the complex consisting of these interbanded manganiferous rocks and gneisses is surrounded by and invaded by porphyritic biotite-granite.

Finally, it remains to give a list of the rocks found intrusive in the rocks of the gondite series. They are nearly all coarse-grained rocks, allied to pegmatite, and owe their peculiar composition as regards the minerals they contain to the fact that they have passed through rocks

containing manganese before they reached their present position. The following is a list of these intrusives :—

List of rocks intrusive in the rocks of the gondite series.

In the Central Provinces :—
- Pegmatite (Rámdongri).
- Spessartite-pegmatite (Bichua, Ghoti, and Sátak).
- Pyroxene-(brown)-pegmatite (Sítapathúr).
- Quartz-felspar-rock with a brown mineral (Thirori).
- Felspar-rock with spessartite (Hatora).
- Microcline-rock with spessartite and quartz (Beldongri).
- Microcline-rock with brown pyroxene and bronze-coloured mica (Kosumbah).
- Albite-rock with braunite, blanfordite, juddite, and sometimes quartz (Kácharwáhi).
- Blanfordite-granite (Rámdongri).

In Jhábua :—
- Quartz-oligoclase-albite-carpholite(?)-rock (Kájlidongri).
  It is uncertain whether this rock is to be classified with the intrusives or with the mineral veins; it is here put in the former class on account of the presence of felspar, although felspar is also sometimes found in mineral veins.

In Nárukot :—
- Granite vein containing red garnet and a little pyroxene with pink and green pleochroism.
- Granite vein with blanfordite, greenovite, and garnet.
- Quartz-felspar(microcline and oligoclase)-rock.
- Porphyritic biotite-granite.

In addition to the rocks enumerated above, which are found in the masses of the gondite series as veins or irregular patches, and are to be regarded as the products of the intrusion and subsequent solidification of igneous or aqueo-igneous magmas, there is another set of vein-rocks that are probably to be regarded as true mineral veins deposited by mineralized waters percolating along cracks or fissures. The following is a list of such veins :—

List of the mineral veins found traversing the rocks of the gondite series.

In the Central Provinces :—
- Quartz.
- Quartz with spessartite(?) (Bichua)
- Quartz with magnetite (Sítapathúr).
- Tourmaline-quartz-rock(?) (Kodegáon).
- Pyrite in quartz(?) (Kodegáon).
- Opal (Kodegáon and Kándri).
- Chalcedony (Kándri).
- Hematite (Mansar Extension).

In Jhábua (at Kájlidongri) :—
- Hollandite and quartz.
- Hematite and quartz.
- Barytes and quartz, with an arsenate.
- Quartz with angular inclusions of psilomelane.

In Nárukot :—
- None.

It will be seen from the lists given on the preceding pages what a great variety of rocks there is, both constituting, and associated with, the manganese-silicate-rocks to which the name of the gondite series has been given. It will obviously be impossible for me to give here a full petrological account of this large number of rocks, interesting though they be, and I shall content myself with giving a short account of the most important varieties.

Although the number of kinds of rock enumerated above is very large, yet only a few of them are of frequent occurrence. These *more frequently occurring rocks* have been indicated by being printed in *italic type* in the lists given on pages 329 to 332.

Descriptions of the more Important Rocks.

Gondite.

The commonest and most characteristic member of the gondite series, and consequently the one to which the name *gondite* has been given, is one made up of a mixture of manganese-garnet and quartz. Although this garnet has not the theoretical composition of spessartite, yet, if one can judge from two analyses (one of which was calculated from a rock analysis; see page 351), it is sufficiently close to be included under this name. The typical variety of gondite is a fine-grained rock of uniform grain, the separate grains of which are just apparent to the unaided eye. In colour this rock varies from cream-coloured (this being a rare colour) through grey, yellow, buff, and cinnamon, to reddish and purplish. Under the microscope it is seen to consist of very numerous small idiomorphic garnets, in some parts isolated one from the other and in other parts aggregated into little groups, scattered through a matrix of mosaic quartz, the individual grains of which are usually of about the same average size as the garnets. In colour the garnets are of some shade of yellow, varying in thin sections from quite a strong sulphur-yellow to practically colourless. When the nicols are crossed, a very pretty effect is produced owing to the numerous uniformly-sized garnets appearing as dark spots scattered through a matrix of mosaic quartz polarizing in greys and whites. The appearance of this typical gondite is well shown in the photo-micrograph (Plate 11, figs. 1 and 2). Frequently no other minerals can be detected in a thin section of gondite; but just as often a careful examination of the section reveals the presence of a certain number of very small idiomorphic granules of apatite scattered through the quartz mosaic and sometimes also included in the spessartite. In one case, namely, that illustrated in

the photo-micrograph (Plate 11, fig. 2). there is also a small amount of rutile present in the rock. The garnets are usually isotropic, but not infrequently, owing no doubt to strain effects, they exhibit anomalous double refraction.

The relative proportions of the two constituents of gondite vary between very wide limits, so that there is every gradation between quartz-rock free from spessartite and spessartite-rock free from quartz. The typical rock, however, may be regarded as that which contains about equal proportions of the two constituents. The microscope shows that those varieties that show purplish or reddish tints in the hand-specimen do not as a rule owe their colour to the garnet being purple or red; but to the fact that the separate grains of garnet each contain a small cloud of finely-divided red dust, probably oxide of iron, sometimes uniformly distributed throughout the grain, but more often collected in the central parts of the grain so as to leave the periphery clear. The other variations of colour seem, however, to be due to variations in the colour of the spessartite, which may range from almost colourless through pale yellow, bright yellow, and orange, to orange-red, or even deep blood-red. This variation in colour is no doubt due to variations in the amounts of manganese and iron in the garnet. The fine-grained variety described above is perhaps the commonest variety of gondite and is to be regarded as the typical rock. From this degree of fine grain there is every gradation up to varieties of gondite of very coarse grain in which the garnets may be as much as 1 or even 2 inches in diameter. In these more coarsely crystalline varieties the garnets are often well developed so as to show their crystalline form. This is almost invariably seen to be the simple trapezohedron or icosatetrahedron, although other faces, for an account of which see the mineralogical description of this mineral (page 172), are not infrequently found. Dana's 'System of Mineralogy' does not indicate that particular varieties of garnet favour particular mineral habits. My experience, however, of the Indian garnets points to the fact that if a garnet exhibit predominant trapezohedral faces it is almost certain to give a strong reaction for manganese when fused with nitre and fusion mixture. In fact, in the Central Provinces one would almost invariably be correct if one designated all garnets exhibiting predominant trapezohedral faces as manganese-garnets, and all garnets in which other faces predominate as garnets practically free from manganese and far removed from spessartite in composition. There are exceptions to this rule, as is evident from the fact that a single example of an octahedral spessartite-garnet

EXPLANATION OF PLATE 11.

PHOTOMICROGRAPHS.

FIG. 1.—Shows numerous small garnets (spessartite) in a matrix of fine-grained quartz (light).

FIG. 2.—Shows spessartite-garnets tending to be idiomorphic, in a clear matrix of quartz. Occasional dark grains of rutile are also present.

FIG. 3.—The dark mineral is spessartite and the light one quartz.

FIG. 4.—Crossing the nicols brings out the strained structure of the quartz mosaic, which appears uniform in figure 3.

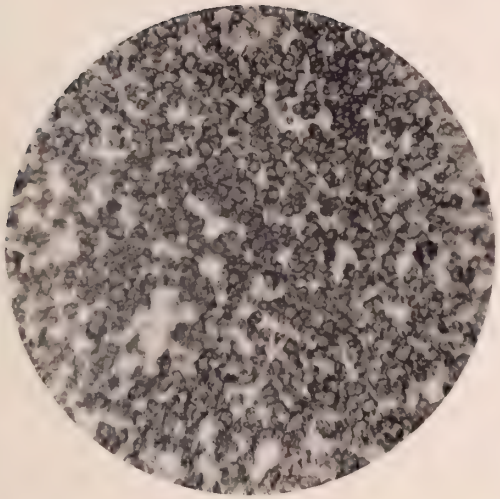


Fig. 1.—× 23.
Very fine-grained gondite.
Jothvád, Nárukot State, Bombay.

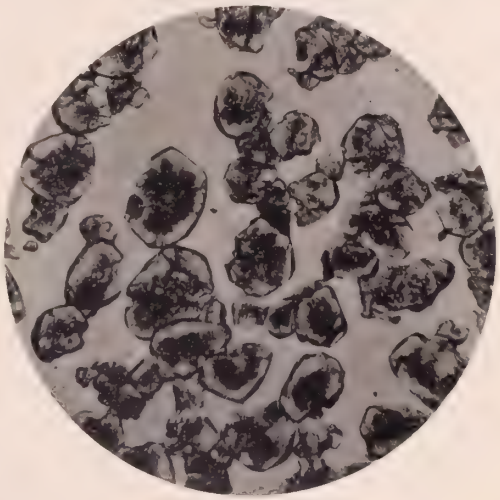
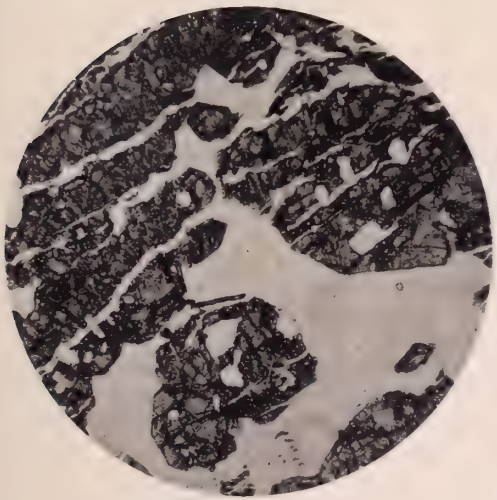
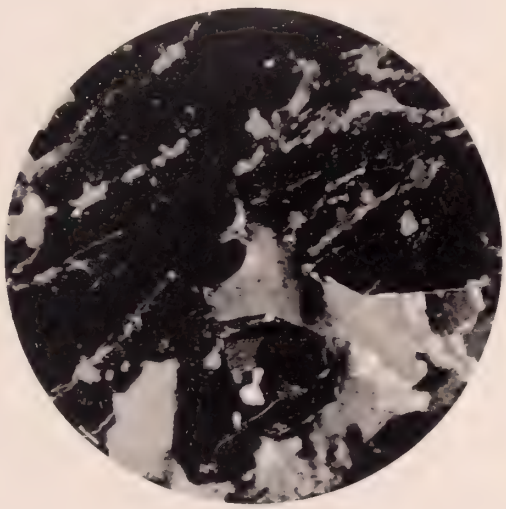


Fig. 2.—× 23.
Typical gondite.
Wagora, Chhindwára district, C.P.



L. L. Fermor, Photomicrograph.

Fig. 3.—× 23.
Strained gondite by ordinary light.
Rámdongri Nágpur district, C.P.



Bemrose, Collo., Derby.

Fig. 4.—× 23.
Same as Fig. 3, but with nicols crossed.

has been found at Chárgáon. In these coarsely crystallized varieties the garnet varies from bright yellow to orange and orange-red.

Apatite-gondite.

An examination of sections of gondite under the microscope sometimes shows that apatite is present in considerable abundance. The rock can then be designated apatite-gondite. This variety is not, however, common, and no example has yet been found in which the apatite is conspicuous in the hand-specimen.

The rhodonite-bearing members of the series.

Less common than gondite and spessartite-rock are those varieties of the series characterized by the presence of rhodonite in considerable or predominant proportion. Of these the most abundant is a rock composed of a mixture of spessartite and rhodonite with or without quartz. The rocks containing rhodonite are never so fine-grained as the typical gondite. When composed entirely of rhodonite, or nearly so, they have a saccharoidal appearance resembling that of a crystalline limestone, although the colour is, of course, not white, but rose-pink when fresh. Under the microscope this rhodonite rock appears as an aggregate of roughly equi-dimensional crystals; they are allotriomorphic in outline owing to the fact that they are pressed one against the other, except that there is a tendency for them to be somewhat elongated in the direction of the well-marked prismatic cleavage. A photo-micrograph of such a rock is given in Plate 12, fig. 3. More frequently, however, the rock does not consist entirely of rhodonite, but contains spessartite in either small or large proportion. When in small proportion the spessartite appears in the hand-specimen as rich orange-coloured rounded granules or crystals set in the pink rhodonitic matrix, the whole forming a most beautiful combination. In this rock the spessartite is often idiomorphically developed, sometimes as almost perfect trapezohedra, which are occasionally glass clear and then of the beautiful rich orange colour mentioned above. Under the microscope it is seen that the garnet is as a rule idiomorphic towards the rhodonite, which tends to enclose it. The proportion of spessartite may increase until it predominates over the rhodonite. In this case also the garnet tends to be idiomorphically developed with regard to the rhodonite, although in one or two cases I have noticed under the microscope more or less rounded crystals of rhodonite enclosed in the spessartite. In two cases I found this rhodonite-spessartite-rock to contain a third constituent, of white colour, which was found on testing to be *barytes*. This constituent had every appearance of being an original constituent of the rock

Barytes in the gondite series.

as far as one could judge from its relations to the other components. If this be the case, we must suppose that the original sediments from which the gondite series was produced were in some cases highly barytiferous. This conclusion is supported by the high percentage of this element found in many of the ores ; although, if the supposed original barytes were not present, it might be supposed that the barium had been subsequently introduced. There is, however. nothing contrary to the experience of the present day in making this supposition that the original sediments contained barium ; for we have an actual example in our own Indian seas, namely that described by E. J. Jones[1] of some nodules obtained by trawling off Colombo in water of 675 fathoms. These nodules were found on examination to consist almost entirely of barytes, one of them giving 82·5 per cent. $BaSO_4$ on analysis. One is very apt to overlook the presence of barytes in a rock when it is not presence in abundance. There are four minerals in the gondite series that require some care in distinguishing. These are orthoclase, apatite, barytes, and arsenates, all colourless minerals with a low or comparatively low birefringence. The felspar can, however, be at once distinguished from the other three substances by noticing the index of refraction ; this can be rendered more obvious by cutting off with the hand a portion of the light coming from the mirror of the microscope, or, if the instrument is provided with an iris diaphragm, by stopping down considerably. When this is done the orthoclase still shows an unpitted surface, while the other three minerals stand up in relief with a much pitted surface. For the method of distinguishing apatite, arsenates, and barytes, one from another see page 220.

Another variety of the rhodonite-spessartite-rock is one containing, in addition to barytes, a *green manganesian phosphate*, for which see page 207. It is surprising that manganiferous phosphates have not been detected more often in the rocks of the gondite series than in this solitary case.

Rhodonite-quartz-rock and rhodonite-gondite.

Both the rhodonite-rock and the rhodonite-spessartite-rock often contain small quantities of quartz, which may increase in quantity until the rock becomes a rhodonite-quartz-rock or a rhodonite-gondite, respectively. All the rhodonite-bearing rocks are distinguished from those free from rhodonite, such as gondite or spessartite-rock, by the fact that they almost invariably occur in layers or beds of a massive character, and do not often occur as

[1] *Rec. Geol. Surv. Ind.*, XXI, p. 35, (1888).

EXPLANATION OF PLATE 12.

PHOTOMICROGRAPHS.

FIG. 1.—The garnets are seen centrally blackened by manganese oxide, and are set in a matrix of mosaic quartz.

FIG. 2.—Spessartite—light; manganese-ore—dark.

FIG. 4.—Pyroxene—light; manganese-ore—black.

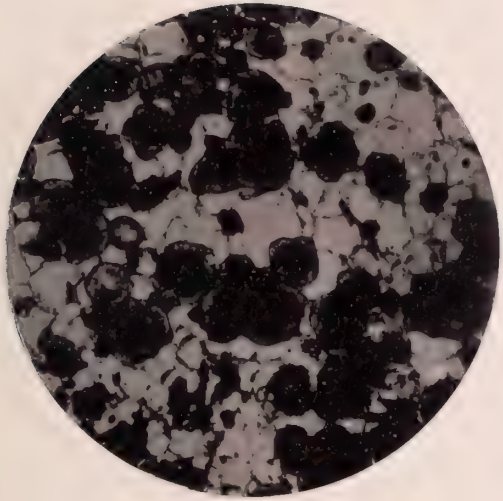


Fig. 1.— × 33.
Gondite, with garnets altering.
Ukua, Bálághát district C. P.

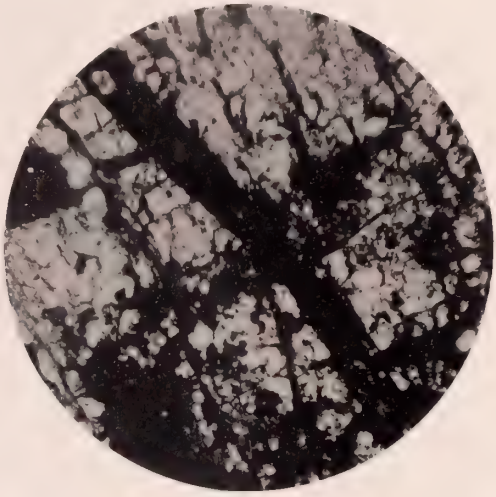
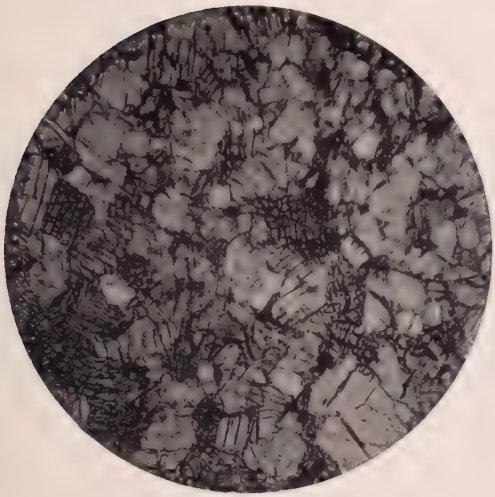
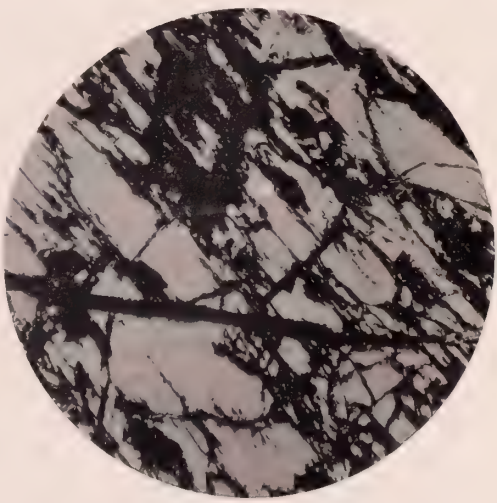


Fig. 2.— × 23.
Spessartite-rock, partially converted into manganese-ore.
Mansar, Nagpur district, C. P.



L. L. Fermor, Photomicrograph

Fig. 3.— × 23.
Rhodonite-rock.
Rámdongri, Nagpur district, C. P.



Benrose, Collo., Derby.

Fig. 4.— × 23.
Pyroxene (Rhodonite?), altering to manganese-ore.
Kodur, Vizagapatam district, Madras.

thin layers interbanded with equally thin layers of quartzite or quartz, as is so often the case with the rocks free from rhodonite.

The amphibole-bearing members of the series.

Not unfrequently members of the gondite series contain small rosettes of a fibrous mineral, which, when fresh, seems to vary in colour from greenish grey to white, but which is more often altered to a brownish colour, usually some shade of chocolate. This alteration is seen under the microscope, to be due to the deposition along cleavage cracks of brown and black oxides, probably of manganese and iron. The mineral has not yet been critically examined, but is in all probability some variety of the amphibole group. It is found more often in the rocks containing rhodonite, with which it is sometimes seen under the microscope to be in parallel growth, than in those free from this mineral.

Rhodochrosite in the gondite series.

At two localities, rhodochrosite has been definitely identified in rocks belonging to this series; whilst in many other cases small quantities of rhombohedral carbonates, formed in all probability by secondary changes from the manganese minerals with which they are associated, have been noticed in thin sections. In the two cases of Gaimukh and Devi, however, the rhodochrosite may be an original mineral formed at the time of metamorphism of the original sediments.

Felspar in the gondite series.

From the lists of rocks occurring in the gondite series as given on pages 329 and 330, it will seem as if these rocks frequently contain felspar. Such, however, is not the case, for each of the felspathic rocks mentioned has been found at only one, or at the most two, localities. In the Central Provinces at least, the felspar bearing members of this series are very rarely found. In the Central Provinces the felspar may be either orthoclase or microcline, whilst in Jhábua both orthoclase and plagioclase have been noticed. At Nárukot only plagioclase has been found and this but rarely. It is this rarity of felspar in the gondite series that not only distinguishes it from the kodurite series, but is also an argument against the gondite series being of igneous origin.

Piedmontite, calcite, and wollastonite, in the gondite series.

It will be seen from the list given on page 329 that piedmontite has not been found in the gondite series as represented in the typical area, namely the Central Provinces. This is because the piedmontite-bearing rocks, being associated with crystalline limestones, are found quite apart from the masses of the gondite series as defined on page 307. In Jhábua and

Nárukot, however, the calcareous manganiferous sediments were deposited in such intimate association with the arenaceous and argillaceous manganiferous sediments that it is impossible to separate them now that they have been folded together and metamorphosed. The consequence is that in both these areas piedmontite-bearing members of the gondite series are found, together with other rocks characterized by a high percentage of calcareous matter. Thus in Jhábua there are the rocks containing winchite and calcite, and in Nárukot rocks containing calcite and wollastonite.

Arsenates in the gondite series.

In both the Central Provinces and Jhábua arsenates have been found forming important constituents in masses of rock belonging to this series. In the one case in the Central Provinces, namely at Sitapár in the Chhindwára district, the arsenate is associated with various manganese-ores, so that in this case it may not have been produced by the direct metamorphism of original sediments, but by the subsequent action of mineralized waters. This, however, is by no means certainly the case, and, from the nature of the minerals with which the arsenate is associated, it is quite possible that the arsenate and the minerals with which it occurs are the products of the metamorphism of sediments containing arsenic, the metamorphic processes having possibly been aided by circulating waters bringing about a concentration of the perhaps originally more uniformly distributed arsenic. In the other case of a rock containing an arsenate, namely at Kájlidongri in Jhábua, the rock must be regarded as the direct product of metamorphism of the original sediments, for it is in all respects like other members of this series, except that it contains an arsenate as a very important constituent. The exact composition of these arsenates has not yet been determined, but calcium and magnesium seem to be important constituents in Jhábua and calcium in the Central Provinces.[1]

Pyroxenes in the gondite series.

Besides rhodonite, other pyroxenes are sometimes, though very rarely, found in the rocks of this series. These pyroxenes have not yet been examined in detail, but as seen under the microscope they usually show not very strongly marked pleochroism in shades of yellow and brown, so that they may be allied to the manganese-pyroxene, schefferite. Such pyroxenes are especially abundant at Jothvád in Nárukot, but have also been found in the Central Provinces and Jhábua.

[1] The Sitapár mineral is partly phosphate.

Blanfordite.

The pyroxene showing the beautiful type of pleochroism in pink, blue, and lilac, has not been found in the typical rocks of this series as given in the list on pages 329 and 330; but it is a rather frequent constituent of the manganiferous micaceous schists associated with the gondite series in Nárukot and Jhábua and with the winchite-bearing rocks in Jhábua.

The manganiferous micaceous schists are not of sufficiently frequent occurrence to be further discussed here, but it will be as well to give a short account of some of the quartzites associated with the rocks of the gondite series.

Black quartzite.

A rock very frequently met with in the manganese-ore deposits of the Central Provinces is a black fine-grained quartzite, which is somewhat heavier than an ordinary quartzite and usually occurs interbanded with manganese-ore, for which it can, at first sight, often be mistaken. Under the microscope it is seen to owe its peculiar characters to the presence of a large number of minute inclusions. The rock itself is very fine-grained, consisting of a quartz mosaic through which are scattered clouds of tiny black bodies. These are evidently minute crystals of some definite mineral, for they are seen with a high power to be prisms or rods that show in cross sections as little rounded or polygonal bodies. Since the rock when powdered and fused with nitre and fusion mixture gives a fairly strong reaction for manganese, it is probable that these inclusions consist of some manganese mineral. Plate 13, fig. 1 shows a photo-micrograph of a specimen of this rock from Bálághát. In this section the inclusions are especially abundant: but specimens can be found showing every gradation between this rock and quartzite practically free from such inclusions, there being a corresponding gradation in colour from black to white. Such rocks are to be regarded as the products of the metamorphism of arenaceous sediments containing varying amounts of admixed manganese oxide; for, considering the intimate way in which the little idiomorphic prisms are scattered throughout all the grains of quartz, it is not probable that the manganese oxide has been introduced subsequent to the formation of the quartzite. Some manganiferous quartzites are, however, formed in this way. But in the rock so formed the manganese-ore is distributed in rounded patches. As an example attention may be drawn to the photo-micrograph of such a rock from Sivarájpur in the Panch Mahals, Bombay, shown in fig. 1 of Plate 10. Other localities for the black quartzites are Kodegáon,

Manegáon, Rámdongri, and Waregáon, all in the Nágpur district. Sometimes the manganese-ore in these quartzites occurs in small patches rather than in separate needles, as in fig. 2 of Plate 13. This section also shows what looks like a cavity lined with delicate black needles of a manganese mineral. Crossing the nicols shows, however, that this supposed cavity is really filled with mosaic quartz into which the needles project.

Red quartzite.

Bright brick-red quartzites are also of fairly frequent occurrence, as, for example, at Bálághát, Ukua, and Kájlidongri. Like the black quartzites, these red varieties are very fine-grained, so that under the microscope they show a fine mosaic. The red colour is then seen to be due to the presence in the interior of each grain of a small cloud, usually collected towards the centre, of a red dust, which is in all probability ferric oxide or finely divided hematite. That it does occur inside the separate grains and not along their junctions is shown by the fact that if a piece of the rock be powdered and boiled with hydrochloric acid it does not lose its colour. If, however, the rock be finely powdered and fused with fusion mixture the iron can be extracted.

Manganiferous gneisses.

At both Kándri and Mansar there is a rock, which occurs in close association with the ore-body, that looks at first sight like a rather fine-grained quartzite. It is pinkish to whitish in colour. A closer examination, however, shows that it is finely crystalline and contains scattered grains and streaks of a black mineral that is magnetic, but not sufficiently so for magnetite ; and since this mineral gives a reaction for manganese it is either manganmagnetite or, less probably, braunite. It will require a separation of a considerable quantity of the mineral before this point can be settled ; for it only occurs in tiny grains in the rock. Under the microscope the rock is seen to consist of a rather fine-grained aggregate of quartz and microcline, and sometimes plagioclase, with fairly abundant scattered granules of the black ore mentioned above. It sometimes, but not often, except near the ore-body, contains a little yellow garnet, presumably spessartite, in streaks ; more often it glistens in the hand-specimen from the presence of fairly abundant scales of muscovite-mica, although this last constituent may be entirely absent. The rock may be called a manganiferous gneiss, or even manganmagnetite-gneiss, and has probably resulted from the metamorphism of sediments that were deposited immediately before

EXPLANATION OF PLATE 13.

PHOTOMICROGRAPHS.

FIG. 1.—Shows innumerable black prisms of a black manganese mineral, scattered through a matrix of fine-grained mosaic quartz.

FIG. 2.—The apparent cavity with inwardly projecting needles is really filled with quartz mosaic, as can be seen when the nicols are crossed.

FIG. 3.—Quartz—white; psilomelane—black.

FIG. 4.—The quartz is clear white, whilst the felspar has its cleavage picked out by thin films of manganese oxide (black) deposited along the cleavage planes.

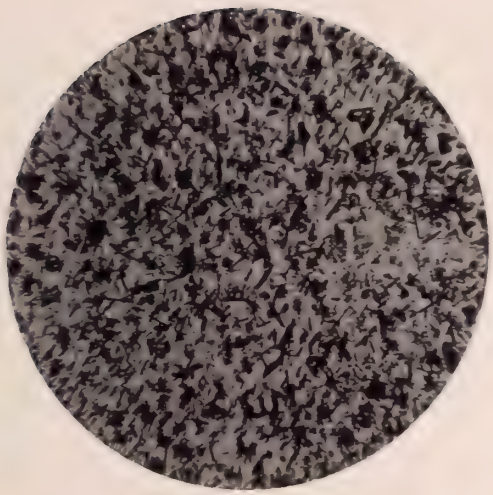


Fig. 1.— × 60.
Black manganiferous quartzite.
Balághat mine. Bálaghat district. C. P.

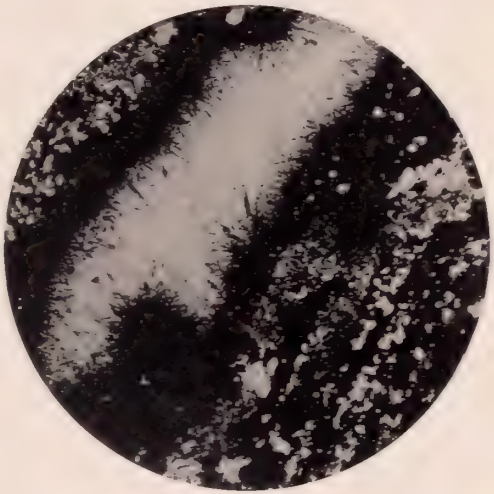
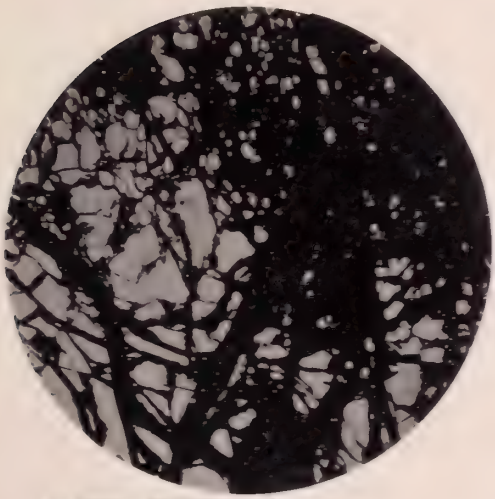
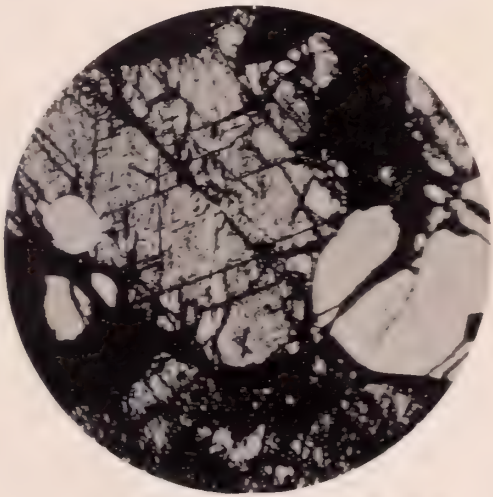


Fig. 2.— × 16.
Black manganiferous quartzite.
Mánegaon. Nagpur district. C. P.



L. L. Fermor Photomicrograph.

Fig. 3.— × 23.
Vein-quartz being replaced by psilomelane.
Chik Vadvati, Dharwár district. Bombay.



Bemrose, Photo., Derby.

Fig. 4.— × 23.
Quartz-felspar rock being replaced by manganese-ore.
Garbham. Vizagapatam district. Madras.

and after the layers of sediment that gave rise to the manganese-ore deposit. The sediment must have been unusually rich in alkalies, probably in the form of felspar derived from the disintegration of older granitic or gneissic rocks. The sediments must also have contained a small proportion of oxides of iron and manganese, the presence of which may be taken as indicating that the change from the conditions under which the main mass of the manganese oxides was deposited, to that under which practically non-manganiferous sediments were deposited, was not abrupt, but was marked by a period of deposition during which the mechanically deposited sediments were mixed with a little chemically deposited manganese oxides.

Localities for the Rocks of the Gondite Series.

I will now give a list showing the localities at which the various rocks of the gondite series have been found. This list will only refer to the Central Provinces because the lists already given for Jhábua and Nárukot each refer to one locality only. Localities will only be given for those of the associated rocks that are not of common occurrence, as the others are found at many localities.

List of localities for the members of the gondite series in the Central Provinces.

Gondite :—At almost every occurrence of the rocks of this series; but Chikhla I, Wagora, Gumgáon, and Mansar, may be specified as specially good localities.

Spessartite-rock :—At almost every place where gondite is found, but in much less abundance. The following localities are specially good :—Hatora, Chárgáon, Mándri, Mánegáon, and Pársioni.

Rhodonite-gondite :—Sonegáon, Thirori, Devi, Guguldoho, Pársioni, Rámdongri, Sátak I.

Rhodonite-spessartite-rock :—Gaimukh, Ghoti, Beldongri, Mánegáon, Panchála, Waregáon.

Apatite-gondite :—Guguldoho.

Apatite-spessartite-rock :—Guguldoho, Kándri, Mándri.

Amphibole-gondite :—Chándadoh, Chikmára, Hatora.

Amphibole-spessartite-rock :—Hatora, Mándri, Pársioni.

Amphibole-rhodonite-gondite :—Bichua.

Amphibole-spessartite-rhodonite-rock :—Pársioni, Sitagondi.

Amphibole-apatite-gondite :—Nandapuri.

Magnetite-gondite :—Kachi Dhána, Kodegáon.

Magnetite-spessartite-rock :—Kachi Dhána.

Rhodochrosite-gondite :—Gaimukh.

Rhodochrosite-spessartite-rhodonite-rock :—Gaimukh.

Rhodochrosite-rhodonite-rock :—Devi, Gaimukh, Guguldoho (?)

Orthoclase-gondite :—Kachi Dhána

Spessartite-orthoclase-rock :—Kándri.

Microcline-gondite :—Kachi Dhána, Kándri.

Pyroxene-microcline-gondite :—Sukli.

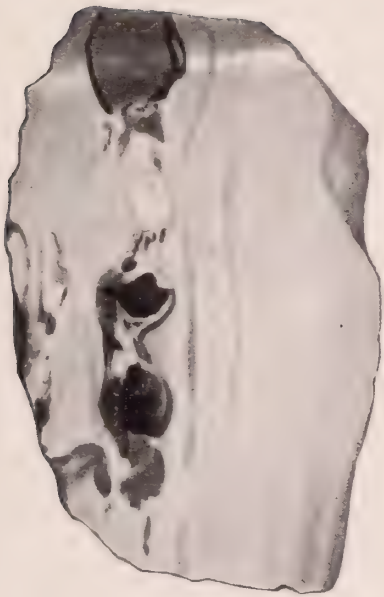
Apatite-felspar-spessartite-rock with mica :—Sátak I.
Orthoclase-amphibole-rhodonite-gondite with rhodochrosite (?) :—Pársioni.
Rhodonite-quartz-rock :—Guguldoho.
Rhodonite-rock :—Asalpáni, Wagora, Guguldoho, Mánegáon, Panchála, Risára, Sitagondi.
Rhodonite-rock with magnetite, spessartite, and manganese-mica :—Rámdongri.
Barytes-spessartite-rhodonite-rock :—Ghoti.
Barytes-spessartite-rhodonite-rock with a manganesian phosphate :—Chárgáon.

Of the associated rocks localities may be given for the following less common types:—

Pyroxenic quartzites :—Beldongri, Junawáni, Waregáon.
Spessartiferous quartzites :—Chikhla I. Kándri. Kodegáon, Mansar Extension, Parsoda
Manganiferous micaceous schists :—Kácharwáhi.
Hematite (manganiferous)-quartz-rock :—Ramrama.
Manganiferous gneiss containing manganmagnetite :—Kándri, Mansar.
Manganese-mica-quartz-schist :—Sitapathúr.
Ottrelite-mica-schist :—Bálághát, Sítasáongi.
Hematite-quartzite :—Thirori, Mansar Extension.
Martite-quartzite :—Hatora.
Magnetite-muscovite-quartz-schist :—Hatora.
Hornblendic quartz-pyroxene-gneiss :—Sukli.
Sapphirine (?)-enstatite-quartzite :—Chikhla I.

Areas to prospect for further occurrences of the gondite series.

Since it has been possible to assign the rocks and ores of the gondite series to a definite system, namely the Dhárwárs, it should be possible to indicate in what areas future prospecting should be carried out for the purpose of finding further occurrences of these rocks. In the first place, since the occurrences of this series that have been found in the less metamorphosed type of the Dhárwárs, known in the Central Provinces as the Chilpi Ghát Series, have all been found to occur near what seems to be the base of the series, the attention of prospectors might well be directed to the boundaries of this formation as mapped in the southern parts of the Bálághát district and the northern parts of the Bhandára district (see Plate 43). It does not, of course, follow that such work would be successful; in the first place because the areas indicated may have been outside the limits within which manganiferous sediments were deposited; and in the second place because any occurrences of the rocks of this series might all be in the condition of unaltered manganese-silicate-rocks, such as gondite and rhodonite-rock, and consequently not worth working as a source of manganese under present conditions of metallurgical treatment. A reference to the map of the Nágpur-Bálághát area will also show that the extreme northern portions of the Nágpur district, namely those parts lying to the north of Chorbáoli and Junawáni, and the extreme southern portions of the Seoni district, lying between the Pench river on the west and Katangi in the Bálághát district on the east, together



From a sepia drawing.

PIEDMONTITE AND MANGANESE-ORE NODULES IN A PIEDMONTITE LIMESTONE.

AROUND THE MANGANESE-ORE NODULE IS A THIN RIM OF PIEDMONTITE.

½ NATURAL SIZE.

form an area lying between the manganese areas of the Chhindwára district and western Bálághát. This area might well be examined with considerable prospects of success. If any deposits be located in this area it will in some cases probably be found cheaper to transport the ores north to the Chhindwára-Seoni portion of the Sátpura Railway rather than to carry them south to the main line of the Bengal Nágpur Railway.

In Jhábua prospecting for further occurrences of the gondite series should be directed to the extension towards the north and north-north-west of the Arávalli rocks occurring in the Rambhápur area. Some unimportant deposits of manganese-ore have already been discovered on this line of strike. It will be seen from the geological map of India that the Arávallis of this area are probably continuous with the main outcrops of this system in Rájputána. Hence prospecting in the portions of Rájputána lying to the north of Jhábua, as, for example, in the State of Banswára, might have some prospects of success. Indeed, I am told that manganese-ore of inferior quality has already been found in Banswára. A more extended examination of the metamorphic and crystalline area of Nárukot and the adjoining portions of the Rewa Kántha area might reveal the presence of manganese-ores. Similarly all the areas of Dhárwár, Arávalli, Chámpáner, or Chilpi, rocks in India might yield, on careful prospecting, further deposits of manganese-ore, as also any portions of the metamorphic and crystalline complex that are suspected to contain rocks of Dhárwár age folded in with the older rocks.

CHAPTER XVII.

GEOLOGY—*continued.*

The Gondite Series—*concluded.*

Chemical composition—Alteration of the gondite series—Evidence of alteration—Time of alteration—Method of alteration—Depths to which the ores extend—Conclusions as to the origin of the gondite series and associated manganese-ores.

Chemical Composition of the Gondite Series.

Composition of gondite.

As can be judged from the list of rocks given on page 329, the composition of the rocks of the gondite series is very variable, and I propose to consider here only a few of the less complex members. As has been already mentioned, the type rock of this series may show every gradation in composition between quartz-rock free from spessartite and spessartite-rock free from quartz, *i.e.* between SiO_2 and $3(Mn,Fe,Mg,Ca)O.(Al,Fe,Mn)_2O_3.3SiO_2$, assuming this to be the composition of the manganese-garnet of the Central Provinces. In a case in which the garnet had the theoretical composition of spessartite the composition of spessartite-rock would be as follows :—

MnO . . .	42·92
Al_2O_3 . . .	20·58
SiO_2 . . .	36·50

Gondite composed of equal parts of quartz and spessartite, in one case by weight and in the other by volume, would have the composition shown below :—

	Equal parts by weight.	Equal parts by volume.
MnO	21·46	26·25
Al_2O_3	10·29	12·57
SiO_2	68·25	61·18
	100·00	100·00

An actual analysis was made of a piece of typical gondite (16·984) from Wagora in the Chhindwára district. This is the rock of which a photomicrograph is given on Plate 11, fig. 2. It is a cinnamon-pink or pinkish buff rock of fine grain. The specific gravity of the piece analysed was found to be 3·42. Under the microscope the rock is seen to

be composed almost entirely of quartz and garnet with a small quantity of apatite and rutile. The analysis was made by Messrs. J. and H. S. Pattinson of Newcastle, the weight of the piece of rock ground up for this purpose being 42·23 grammes. The result of the analysis is shown below :—

Analysis of typical gondite from Wagora, Chhindwára district.

G. = 3·42. No. 16·984.

MnO	13·37
Fe_2O_3	7·47
FeO	0·13
Al_2O_3	12·36
CaO	2·60
MgO	1·90
K_2O	0·03
Na_2O	0·19
SiO_2(combined)	20·60
SiO_2(free)	39·85
P_2O_5	0·68
CuO	0·02
TiO_2	0·46
Cl	Trace.
Combined water	0·20
Moisture at 100°C.	0·10
	99·96
Manganese	10·36
Iron	5·33
Silica (total)	60·45
Phosphorus	0·30

The process adopted in calculating this analysis into terms of the mineral composition of the rock is to first take out the titania (TiO_2) as rutile, and next to take the lime (CaO) necessary for the formation of apatite with the phosphoric oxide (P_2O_5), the required amount of chlorine or fluorine being assumed to be present. The free silica is all assumed to be in the form of quartz, as there was no evidence of the presence of any other form of free silica such as chalcedony. There are then two methods that may be adopted in dealing with the remainder of the constituents. In either case the cupric oxide (CuO), combined water, and moisture, are not considered, but are regarded as impurities.

The alternatives are either to regard the potash and soda as impurities, or to suppose that they are present as felspar. Taking the first alternative (I) and thus regarding the combined silica as all present in the garnet, this silica is used as the basis of calculation. More than sufficient alumina (Al_2O_3) is present for the formation of spessartite, so that

all the other oxides must be present in the protoxide portion of the garnet, for which there is not enough manganese protoxide (MnO). For this reason it is necessary to regard the larger portion of the iron as forming a part of the protoxide portion of the garnet, although the iron is mostly returned as being in the form of ferric oxide (Fe_2O_3). The other alternative (II) is to regard the alkalies as present in the form of orthoclase and albite, although neither felspar is visible under the microscope. For it does not follow that there is not present in the rock the very small proportion of felspar to which the alkalies present correspond; for such a small quantity of felspar might easily be overlooked, especially if not twinned. After setting aside the amounts of alumina and silica required for the felspar, the remaining constituents can be combined as garnet in the same way as in the former case; but the analysis does not then work out so well, because there is then a larger amount of ferric oxide and alumina left over unaccounted for. It would of course be possible to calculate a portion of this residue as a further amount of garnet by taking a little of the silica that has been entered up in the analysis as free silica. The following shows the mineralogical composition of the rock according to these two methods of calculation :—

I			II		
Rutile		0·46	Rutile		0·46
Apatite		1·58	Apatite		1·58
Spessartite :—			Spessartite :—		
MnO	13·37		MnO	13·37	
FeO	5·43		FeO	3·97	
CaO	1·70		CaO	1·70	
MgO	1·90		MgO	1·90	
Al_2O_3	11·89		Al_2O_3	10·91	
SiO_2	20·60		SiO_2	19·38	
	54·89	54·89		51·23	51·23
Fe_2O_3		1·58	Fe_2O_3		3·20
Al_2O_3		0·47	Al_2O_3		1·11
Surplus oxygen		0·59	Surplus oxygen		0·43
K_2O		0·03	Orthoclase		0·17
Na_2O		0·19	Albite		1·61
Quartz		39·85	Quartz		39·85
CuO		0·02	CuO		0·02
Combined water		0·20	Combined water		0·20
Moisture at 100°C.		0·10	Moisture at 100°C.		0·10
		99·96			99·96

Taking the mineralogical composition of the rock as expressed in column I, and knowing the specific gravities of quartz and of the rock to

be, respectively, 2·65 and 3·42, it is easy to calculate the specific gravity of the remainder, which consists practically entirely of spessartite. The result thus obtained will therefore be very close to the true value for the specific gravity of spessartite—if anything just a trifle too low, because the other constituents mixed up with the garnet are all of lower specific gravity, except the rutile, which has practically the same value for this constant as spessartite. The value thus obtained is 4·24, which may be taken as a very good value for spessartite.

Neglecting all the constituents of the rock except the quartz and spessartite, and calculating to 100, the composition by weight and by volume works out as follows :—

Composition of gondite by weight.		Composition of gondite by volume.	
Spessartite	57·94	Spessartite	46·30
Quartz	42·06	Quartz	53·70

so that the piece of gondite chosen as being typical consists of about equal proportions of quartz and garnet by volume.

From this analysis we can also calculate the composition of the spessartite. This works out to the figures shown in column I below, whilst column II gives the result of an analysis made by Mr. T. R. Blyth, of the Geological Survey of India, of a specimen of manganese-garnet from Chárgáon in the Nágpur district :—

	I Spessartite from Wagora.		II Spessartite from Chárgáon.	
MnO	24·48		30·29	
FeO	9·94	=44·34 MnO	..	=40·82 MnO
CaO	3·11		4·97	
MgO	3·48		2·40	
Al_2O_3	21·26		8·05	
Fe_2O_3	..	=21·26 Al_2O_3	8·38	=19·56 Al_2O_3
Mn_2O_3	..		9·50	
SiO_2	37·73		34·71	
Surplus MgO	..		3·00	
	100·00		101·30	
Oxygen assumed	*Nil*		0·96	
	100·00		100·34	

It will be seen that the analysis of the Chárgáon garnet does not agree very closely with the theoretical composition of garnets, namely that expressed by the general formula $3R''O.R'''_2O_3.3SiO_2$, there being

a surplus of 3 per cent. of magnesia. The state of oxidation of the manganese and iron was not determined, because the quantity of fairly pure garnet separated for analysis was not sufficient for this purpose. Owing, however, to the small quantity of the sesquioxides, Al_2O_3 and Fe_2O_3, it is necessary to assume that a portion of the manganese is present in the form of manganese sesquioxide, Mn_2O_3, in order to form the group R_2O_3 in the garnet formula. This is, of course, somewhat unusual; for manganese is not usually supposed to be present in the sesquioxide portion of garnets, but only in the protoxide portion. The variation in the amount of manganese present in these two garnets is considerable, but the general composition of them is sufficiently near to the standard composition to warrant the use of the term spessartite to designate them. The variation in the amount of manganese present could well account for the variation in the colour of the manganese-garnets of the Central Provinces. In this case it is somewhat difficult to compare the colours of the two garnets, because the Wagora garnet was distributed as small granules in a piece of gondite where its colour was to some extent masked and diluted by the quartz with which it was associated. Nevertheless, I should say that the Wagora garnet was, as would be expected from the smaller percentage of manganese it contains, distinctly paler in colour than the Chárgáon garnet. In the latter case the specimen analysed was obtained by breaking up and carefully picking two or three trapezohedral crystals, which were of a deep orange colour.

Composition of rhodonite-quartz-rock.

The only other member of the gondite series whose composition we need consider is that composed of rhodonite and quartz. Here again it is obvious that the rock may show every variation in composition between that of quartz-rock free from rhodonite and that of rhodonite-rock free from quartz. The Indian rhodonites have not yet been examined analytically, so that it is not known if they conform to the composition of the typical mineral, *i.e.* have the composition expressed by the formula $MnSiO_3$, or if a portion of the manganese is replaced by some other element such as calcium. Assuming the Central Provinces rhodonite to have the theoretical compostition, then the composition of rhodonite-rock would be as follows:—

MnO	54·04
SiO_2	45·96

corresponding to a manganese contents of 41·86. Assuming the specific gravity of rhodonite to be 3·63, the chemical composition of rhodonite-

quartz-rock made up of equal parts of the two minerals by weight and volume, respectively, is shown below :—

	Equal parts by weight.	Equal parts by volume.
MnO . . .	27·02	31·25
SiO_2 . . .	72·98	68·75
Mn . . .	20·93	24·21

In the same way the composition of given mixtures of quartz, rhodonite and spessartite, forming different varieties of rhodonite gondite, could be calculated.

Alteration of the Gondite Series.

Evidence pointing to the Formation of Manganese-ore by the Alteration of Spessartite and Rhodonite.

I have already mentioned that a portion of the ores of the deposits associated with the rocks of the gondite series has been formed by the alteration of various rocks belonging to this series. I propose to give here the evidence on which this statement is based and to consider the way in which the alteration took place.

The Mansar deposit.

In many places the quarrying operations have laid bare masses of gondite or spessartite-rock traversed by a black network of manganese oxide in all stages of consolidation into hard manganese-ore. An especially good locality for this is Mansar, where, in December 1906, there were some good exposures at the western end of the deposit. The solid manganese-ore was separated from the yellow spessartite-rock by very irregular boundaries, which had no relation to the bedding planes of the rock. From these masses of manganese-ore, veinlets of ore were seen to branch out into the yellow rock and there form anastomosing networks, which in some places ran together to form small masses of ore similar to the larger masses from which the veinlets came. In other places the rock was almost entirely black, with small irregular yellow patches, which looked as if they were the residuum of a rock that was once all yellow. The deduction that the original rock was all yellow and composed of spessartite, with a certain amount of quartz in places, is confirmed by a study of these rocks under the

microscope. On Plate 12, figure 2, is shown a photo-micrograph of a section of this partially altered spessartite-rock. A reference to this will show that there are irregular patches and veinlets of manganese-ore spreading thoroughout the spessartite. Now there are three possible ways of explaining this association of manganese-ore and spessartite with each other. They are as follows :—

Association of manganese-ore and spessartite.

1. The manganese-ore and the spessartite were formed at the same time, during the metamorphism of the original sediments.
2. The manganese-ore, under the influence of metamorphic agencies accompanied by an influx of silica in solution, has been partially converted into spessartite.
3. The spessartite has been partially altered into manganese-ore, the original rock having been composed entirely of spessartite.

The relations of the two minerals one to another in the section, show that the first explanation cannot be correct. For if it were, one of the minerals should be idiomorphic with regard to the other ; or if the two minerals crystallized at the same time they should be intergrown in a more or less poikilitic manner, or mixed together as a granular aggregate.

If the second explanation were true we should expect to see veins of spessartite traversing the manganese-ore rather than the reverse relation shown by the figure.

By the process of elimination we arrive at the conclusion that the third explanation is probably the correct one. According to this, we should expect to see irregular patches of manganese-ore encroaching on the spessartite, and small veinlets traversing it. The photomicrograph shows that such is the case. The examination of a large number of field exposures and thin sections of rocks has convinced me this is not an isolated example, but that the direction of change is really from garnet to ore and not the reverse. This explains the numerous cases of manganese-ores with irregular patches of spessartiferous rock, often disposed more or less centrally in a block of ore bounded by joint planes. If the change were the reverse, one would expect the manganese-ore patches to be central, and the spessartite being formed by alteration to be peripheral.

Spessartite changes to manganese-ore.

The rhodonite-bearing rocks indicate the same direction of change.

Alteration of rhodonite.

When the rhodonite is coarsely crystalline, a microscope section often shows lines of alteration extending along the cleavage planes of the mineral, and thence spreading out to form networks and patches of ore. The appearance seen is like that shown in figure 4, Plate 12, although this is actually a photo of a pyroxene from the Vizagapatam district. This can be taken as conclusive evidence that, in the case of the rhodonite also, the direction of change is from silicate to ore, and not the reverse.

Time of Alteration of the Manganese-silicate-rocks into Manganese-ores.

As there is, hence, little doubt about the direction of change in these rocks, we can now inquire when the alteration took place. On page 321 I have already mentioned a case of the inclusion of manganese-ore in Archæan granite, and the possibility that this indicates that the alteration of silicate to ore took place, at least in part, in Archæan times. It is of course not possible to say if this also apply to the Central Provinces. It is interesting to note, however, that many of the deposits, such as Mansar, showing spessartite-bearing rocks in every stage of alteration to manganese-ore, crop out in the form of small hills, which on being quarried are found to be remarkably dry and free from water. From this consideration alone I should say that the alteration is not now taking place in such deposits, except, perhaps, for a certain amount of surface oxidation. In the case of the deposits that are buried in the alluvium it is difficult to say if the change is still going on or not. Probably it is to a small extent, considering that there is usually a free influx of water into the deposit. It is a noticeable point, however, that if one traces a band of the gondite series along its strike it is usually found to reach its highest point in places where there are bodies of workable ore, the rock in between consisting of one of the varieties of manganese-silicate-rock, with much less or practically no associated manganese-ore. This is well seen in cases where the manganiferous band crops out continuously above the surface; *e.g.* at Mansar, where the most valuable portion of the deposit also forms the highest portions of the hill-range in which the band is situated; or at Kándri where the rock forming the saddle between North and South hills is composed of gondite, whilst the hills themselves contain fine bodies of workable ore; or at Rámdongri,

Hill deposits are dry.

Highest points of a gondite band consist of manganese-ore.

where the best ores seen *in situ* form the highest portions of hills 4 and 5 (see Plate 24). Now the deposits, the summits of which just reach the surface of the ground, such as several of those on the Dumri-Khandála line of strike, are shown by the quarrying operations to be small hills or hillocks, separated one from another by considerable thicknesses of alluvium, which covers up the lower ground between the hillocks. The character of the ore-bands on this lower ground has not been ascertained; but, on the analogy of the manganiferous bands exposed at the surface, it is not probable that it consists continuously of manganese-ore, but rather that it consists, at least in part, of quite fresh or only partially altered manganese-silicate-rock. Hence it seems probable that, with these deposits also, if the covering of alluvium could be removed, we should find the bodies of manganese-ore forming the hills and hillocks, with manganese-silicate-rocks on the necks between. So that we see that, judging from those deposits that form small hills projecting above the present plains, and probably from those now buried in alluvium, it is necessary to suppose that the bodies of manganese-ore resist the agencies of denudation better than the majority of the manganese-silicate-rocks; the exceptions being the massive rhodonite-rocks, which seem to form just as marked hills as the masses of manganese-ore, as, for example, in the highest portions of Mánegáon Hill. Hence these bodies of manganese-ore must have been formed before the present topography was carved out by the weathering agencies.

I have already mentioned the probability that a portion of the manganese-ores was formed by the direct compression of original manganese-oxide sediments during the Dhárwár folding. Hence it might be these bodies of ore that gave rise to the hills when the rocks were carved out by the weather; whilst the ores formed by alteration of the manganese-silicate-rocks might have been formed subsequent to the present topography. That the latter is probably not the case is shown by the Mansar deposit, where it is evident that the ores have been formed by the alteration of manganese-silicate-rocks, even though they give rise to the highest portion of the hill-range in which the deposit is situated. Hence we arrived at the conclusion that even the ores formed by the alteration of the manganese-silicate-rocks must have been formed largely, if not entirely, before the topography of the country assumed its present shape. This deduction agrees with the dry condition of the hill deposits, mentioned on page 355. This does not tell us, however, whether the ores were all formed in Archæan times on the analogy of

Manganese-ore deposits formed before present topography.

those of Jothvád, or whether the alteration has continued in part almost down to recent times.

Probably formed in Archæan times.

But on page 363 the absence of any except rare open spaces in the ore-bodies is taken as indicating that the larger part of this alteration took place in Archæan times towards the end of the Dhárwár tectonic disturbances.

The Way in which the Manganese-silicate-rocks alter to Manganese-ores.

We can now consider the way in which the alteration of manganese silicate-rock to manganese-ore took place. From the consideration of the rock undergoing alteration and the products of the alteration, it is evident that, in the case of spessartite, the result of the alteration is a removal of :—

(1) most of the alumina ;
(2) a very large proportion of the silica, sufficient of this being left behind for the formation of braunite ;
(3) a certain proportion of the small quantity of lime and magnesia present.

The formation of braunite and psilomelane.

As the manganese was to a large extent present in the garnet in the form of protoxide, there must have also been an introduction of oxygen in solution, this raising the state of oxidation of the manganese. We see from this that the reactions taking place must have been somewhat analogous to those hypothecated to explain the alteration of the kodurite rocks. The formation of braunite might be expressed thus :—

$$11\,(3MnO.Al_2O_3.3SiO_2) + 17O = 3(3Mn_2O_3.MnSiO_3) + 4Mn_2MnO_5 + 11Al_2O_3 + 30SiO_2.$$

Spessartite. Oxygen. Braunite. Psilomelane.

So that the equation should not be too complicated I have put the formulæ of spessartite, braunite, and psilomelane, in their simplest forms. The small amounts of lime and magnesia that enter into the RO group of the spessartite, partly found their way into the psilomelane, replacing a portion of the manganous manganese, and perhaps to a very small extent into the braunite. Any portion of these constituents left over must have been removed in solution. Any ferrous iron in the RO group of the spessartite was no doubt oxidized to the ferric condition. Any manganic manganese in the R_2O_3 group of the spessartite went to form a portion of the braunite or psilomelane, whilst any ferric iron in this group probably went mostly into the braunite and to a smaller

extent into the psilomelane. The psilomelane is represented in the equation as a manganate of manganese of the formula Mn_2MnO_5. The theoretically pure mineral of this composition has not yet been certainly identified : for a portion of the basic manganese is always replaced by calcium, magnesium, iron, derived from the spessartite as explained above ; by hydrogen, derived no doubt from the waters that brought about the alteration of these rocks ; and by barium, which, in the absence of any evidence of its existence in the original spessartite or gondite, must be supposed to have also been brought in by the attacking waters, though possibly only from another part of the deposit ; for as mentioned on page 339, some of the rocks of the gondite series contain barytes. The amounts of alkalies in the Central Provinces psilomelanes are too small to be worth consideration.

From the equation it will be seen that the chief constituents to be removed are the alumina and nearly all the silica.

The ores are not porous.

One result of the removal of the alumina and silica would be that the residual mixture of braunite and psilomelane, formed in accordance with the equation on page 357, would be very porous. For if the following specific gravities be assumed : spessartite, 4·2 ; braunite, 4·8 ; and psilomelane, 4·3 ; then according to the equation, 100 cc. of spessartite would give rise to 29·2 cc. of braunite and 17·6 cc. of psilomelane, so that the total volume of the braunite and psilomelane would be 46·8 cc., or not quite half the volume of the original spessartite. The fact that the masses of ore are no longer porous, except for occasional cavities found in almost all the deposits, can be explained in two ways. In the first place, if the alteration of the ores took place in Archæan times, there may have been subsequent tectonic disturbances sufficiently intense to compact the porous and cavernous masses of ore. I do not, however, think that this explanation would apply to the majority of cases, for the simple reason that I do not think the ores ever were in this porous condition. The examination of numerous microscope sections of gondite in process of alteration has convinced me that the alteration is of the nature of a replacement, in which the incoming solutions add a portion of manganese oxide to that liberated in accordance with the equation given on page 357. The best rock in which to study this replacement is gondite, or spessartite-quartz-rock ; because, in rocks made up entirely of spessartite, it is difficult to distinguish alteration from replacement. In the sections of gondite, it is often

The ores formed by combined replacement and decomposition of spessartite and rhodonite.

seen that the quartz is being bodily replaced by manganese-ore, without the spessartite being appreciably affected. In other sections, in which the change has gone further, it is seen that the spessartite has also suffered replacement, with the production of solid masses of manganese-ore containing residual patches of spessartite. When it comes to the replacement of the garnet the solution seems to have taken advantage of any cracks in the mineral to percolate into its inside and there deposit its manganese oxide. And from these cracks the replacement seems to have spread out in all directions, so that the final result is a mass of manganese-ore with very few or no residual patches of spessartite. When there were no cracks the garnet has been attacked from its exterior, ragged projection of manganese-ore growing into it. It is evident that this replacement-conversion of the garnet into manganese-ore must be a combined decomposition and replacement in which the attacking solutions break up the garnet somewhat on the lines represented in the equation on page 357, and at the same time deposit manganese oxide in the interspaces that would be left if the reaction only proceeded according to that equation; the manganese oxide deposited being thus added to that already in the garnet. This formation of the ores by a combined replacement and breaking up of the garnet means of course that the incoming waters must contain manganese salts in solution. Such manganese was derived, in all probability, from other parts of the deposit where solution was going on instead of deposition. Now in the masses of kodurite many examples are seen of rocks from which the manganese has passed into solution; but in the case of the manganese-ore deposits of the gondite series it is very difficult to point to any particular example or case of gondite or other allied rock from which the manganese has been removed. In figure 1, Plate 12, is shown a photo-micrograph of gondite in which the garnets are each of them suffering alteration with the deposition or liberation of manganese oxide in the interior of each crystal, without the periphery of the crystal being affected. This is possibly a case in which replacement is not going on, for the quartz is practically unaffected. Hence it is possible that it is an example of gondite being attacked under conditions that will permit of the passage of the manganese into solution.

Lack of examples showing solution of manganese.

The next point to be considered is the character of the solutions that were able to dissolve the manganese of the garnet or rhodonite in one part of a mass of rock and deposit it in another part of the same mass

Carbon dioxide as the reagent producing alteration.

with the concomitant decomposition of the garnet and leaching out of the constituents not necessary for the formation of the manganese-ores. Two of the commonest reagents concerned in the formation of mineral deposits are carbon dioxide and sulphuric acid. Considering first the carbon dioxide, we can suppose that in some parts of the mass of gondite or other rock it attacked the rock with the passage of the manganese into solution as bicarbonate, in a way similar to that supposed in the case of the decomposition of spandite (See page 266). This would mean the residual accumulation of the alumina as kaolin mixed with the quartz of the gondite. Kaolinic material is occasionally found in association with the deposits of the gondite series, but only rarely; so that in this respect the theory is not supported by evidence. As in the case of the alteration of the kodurite masses, the solutions must have eventually become saturated with manganese bicarbonate. After this, on coming in contact with the other masses of gondite, the tendency would be for the solutions no longer to dissolve manganese but to deposit it instead, a replacement of the gondite being effected at the same time, with the passage into solution of its silica and alumina. The same difficulty arises as in the case of the kodurite series as to the removal of the alumina, which, according to the experience of the laboratory, would be precipitated in the presence of carbon dioxide or carbonates. As in the case of the kodurite series, we can suppose that under the conditions of the reaction in Nature alumina is slightly soluble in water containing carbon dioxide.

Now let us consider the possibility of sulphuric acid as the reagent that brought about the various changes that have affected the gondite series. In the first place it would be able to remove the alumina in solution in the form of sulphate. Moreover, according to the experiments of Karsten [Comey's 'Dictionary of Solubilities', page 360, (1896)], silica in the form of silicic acid is soluble in sulphuric acid. Further, it is well known that all the oxides of manganese are soluble in concentrated sulphuric acid with the formation of manganous sulphate, often with liberation of oxygen. But in Nature the acid, if present, would probably be dilute, even very dilute. Now the action of dilute sulphuric acid on the various oxides differs. MnO_2 is not attacked at all, whilst Mn_2O_3 and Mn_3O_4 give up a portion of their manganese, so that in each case MnO_2 is left. Hence, during the decomposition of the garnet, if it took place in the presence of solutions of sulphuric acid, any manganous oxide in the RO group would go into solution as $MnSO_4$, whilst any

Sulphuric acid as the reagent producing alteration.

Mn_2O_3 in the R_2O_3 group would be attacked, with the solution of the MnO portion and the leaving behind of the MnO_2 portion. Hence the result of the attack of solutions carrying sulphuric acid would be to remove both the alumina and the silica, and also to remove all the manganese present in the protoxide condition, and a portion of that present in the sesquioxide condition, the residue being the peroxide of manganese. Since the protoxide portion of the spessartite is far more important in quantity than the sesquioxide portion, the result of the attack of sulphuric acid solutions would be the removal of the greater portion of the manganese as manganous sulphate.

Such attack, with the solution of manganese as sulphate, might go on until the solution was saturated with the various substances dissolved. We must then suppose that on coming in contact with a fresh portion of the gondite or spessartite-rock the tendency would be for a further portion of the alumina and silica of the garnet, and of the silica of the quartz, to pass into the solution, with the deposition of a corresponding quantity of manganese oxide, which would be added to the manganese oxide, and other constituents necessary for the formation of manganese-ore, already in the spessartite. In the presence of oxygen in the attacking solutions the formation of the manganese-ores may have taken place according to the equation shown on page 270, in which the Al_2O_3 and SiO_2 passed into solution, with the precipitation of an equivalent amount of MnO, which was converted into a higher state of oxidation by the oxygen. It might be objected that if the attacking solutions contained both manganous sulphate and oxygen, the manganese should have been deposited as oxide without the intervention of the garnet. It must be noticed, however, that the $MnSO_4$ was supposed to have passed into solution by the reverse reaction, which would not be undone except with a change in the conditions; and that the experiments of F. P. Dunnington[1] show that the manganese of manganous sulphate is not precipitated by the action of oxygen alone, but that the presence of some such substance as $CaCO_3$ (which in Nature would probably be found in the form of limestone) is necessary, the deposition then taking place according to the following equation:—

$$MnSO_4 + CaCO_3 + O = CaSO_4 + MnO_2 + CO_2.$$

In this particular case the constituent to take the place of the manganese in the sulphate would be aluminium instead of calcium.

[1] *Amer. Jour. Sci.*, 3rd Series, XXXVI, p. 177, (1888).

Alteration of rhodonite.

For the alteration of rhodonite similar equations to those for spessartite can be formed. Thus the formation of braunite might be represented as follows:—

$$\underset{\text{Rhodonite.}}{7MnSiO_3} + 3O = \underset{\text{Braunite.}}{3Mn_2O_3.MnSiO_3} + 6SiO_2;$$

whilst a somewhat more complicated equation on the lines of that on page 357 could easily be constructed to show the formation of psilomelane. It is to be noticed that these equations are independent of whether the attacking solutions contain CO_2 or H_2SO_4.

Thus it will be seen that either carbon dioxide or sulphuric acid would be able to produce the changes noticed, the sulphuric acid accounting for them more completely on account of its ability to remove alumina in solution: but if the supposition that carbon dioxide can also dissolve alumina under the conditions prevailing in Nature be true, then either reagent would do equally well. Now there is no direct evidence pointing to one as the reagent more than the other. Still, we might look for indirect evidence and see if possible sources for either of these reagents exist in the other rocks forming the Archæan complex in this area. Now a most noticeable feature of this Archæan complex is the rarity of any sulphides, either as constituents of the rocks or as vein-forming minerals,[1] or of any rocks or minerals that may be supposed to have once contained sulphur. All that I have seen are barytes in the gondite series, copper sulphide minerals in basic dyke-rocks and in quartz, and pyrite in a chert vein, all of them being very rare. On the other hand crystalline limestones are found in great abundance and variety in this region. Hence we can suppose that it was carbon dioxide rather than sulphuric acid that brought about the alteration of the gondite series.

Carbon dioxide the more probable reagent.

It is to be noticed that the pyroxenic gneisses of this area are supposed to have been originally impure calcareous sediments; and that in their formation carbon dioxide was liberated: some of this converted portions of the gneisses into calciphyres and crystalline limestones (see page 299): the remainder may have brought about the alteration of the rocks of the gondite series.

[1] Vein-forming sulpher-containing minerals even if present in abundance, would probably have been deposited after the formation of the manganese-ores, if the foregoing theory as to the time of alteration of the gondite series be correct.

Whether the reagent was carbon dioxide or sulphuric acid, there should be loose or cavernous masses of rock left wherever the solvents attacked and dissolved without depositing something in return. But, except for occasional spaces in the ore-body, such cavities are not found. This may possibly mean that the changes took place prior to the last set of compressing earth movements that affected the rocks of this area. If the earth movements that faulted and folded the Gondwána rocks can be supposed to have affected the ancient crystalline rocks to any serious extent, then they would possibly have been sufficient to close up the spaces hypothecated above. But the probability is that these movements would have been insufficient to close up spaces formed in narrow bands of rock that formed but a very small proportion of the already highly compressed and therefore highly resistant rocks of the Archæan complex. Hence if these spaces really did exist and have since been closed up by compression, it is necessary to go back to the series of earth movements that affected all the Archæan rocks at the end of the Dhárwár period. At first sight this may seem to be inconsistent, because these movements have been already called in to explain the metamorphism of the manganese-oxide sediments with the formation of the gondite series. It does not follow, however, that the folding that took place at the end of the Dhárwár period of sedimentation, consisted of one prolonged compressive movement. We can imagine a period of compression during which the more deeply lying portions of the manganiferous sediments were metamorphosed to the condition of the gondite series, followed by a period in which the pressure was released. On referring to page 291 it will be seen that the formation of the manganese silicates, spessartite and rhodonite, involved the liberation of oxygen. It is not necessary that this oxygen should have been removed very far from the compressed rocks, and this may be the very oxygen that, aided by carbon dioxide or sulphuric acid, produced the conversion of a portion of the manganese silicates back into manganese-oxide ores, according to the equations given on pages 357 and 362. This period of diminished pressure may have been of some duration, giving time for the conversion of a considerable proportion of the manganese-silicate-rocks into manganese-ore. Any open spaces thus formed would be closed up by another period of compression, sufficient to close the spaces and yet not sufficient to again convert manganese oxides into silicates. If there be any truth in these considerations then we arrive at the

Rarity of open spaces in the altered rocks.

Further reasons for supposing that alteration took place in Archæan times.

conclusion that the alteration of manganese silicates to manganese-ores took place in Archæan times, this agreeing with the conclusions reached on page 357. Even if this explanation be true it does not follow that a certain further amount of alteration did not take place in post-Archæan times. Indeed it is certain that it has taken place at the outcrops of the gondite series since these rocks were brought to the surface and eroded into their present shape : and very probable that it is still going on at the outcrops ; but the product of this method of alteration is not a compact crystalline ore, but a softish more or less porous one.

Depths to which the Manganese-ores extend.

If the oxygen in the attacking solutions were really that which was expelled from the original manganese-oxide sediments at the time of their metamorphism into silicates, then it is quite evident that, even though the alteration is of the nature of an oxy-alteration, which is usually supposed to be especially characteristic of the surface, this alteration can have taken place at any depth to which the sediments were buried. It may be that in the deepest parts the pressure was not sufficiently ameliorated for the manganese silicates to have been reconverted into oxide. If so, then perhaps the very bottoms of the synclines have escaped this alteration and retained their silicate character. From this we see that when the bodies of manganese-ore are mined, those that were formed by the direct compression of original manganese oxides without any passage through the silicate stage may be expected to extend to as great a depth as the rocks of the gondite series, namely to the bottoms of the synclinal folds. Whilst those that were formed by the alteration of manganese silicates may also extend to as great a depth as the rocks of the gondite series, except that perhaps the very bottoms of the synclines escaped being converted either partially or completely into manganese-ores.

Conclusions as to the Origin of the Gondite Series and the Associated Manganese-ores.

The conclusions at which I have arrived in the foregoing pages are much more open to doubt than those regarding the origin of the ores of the kodurite series, the reason being the smaller amount of evidence obtained. The points that may be considered fairly certain are the following :—

1. The rocks of the gondite series are the product of the metamorphism of the less pure manganiferous sediments of Dhárwár

age, the metamorphism of these sediments having taken place towards the end of the Dhárwár period.

2. A portion of the ores has been formed directly by the compression of the purest of the original manganese-oxide sediments.

3. Another portion of the ores has been formed by the subsequent alteration of the manganese-silicates produced by the above-mentioned metamorphism.

The points that are to be considered as more doubtful are put forth below. Even if they do not express the whole truth, I believe that they form an approximation to it; anyway, together with the points given above, they form a working hypothesis that will suggest to a future geologist the evidence to look for in trying to put the theory as to the origin of these manganese-ore deposits on a surer footing.

4. The ores formed by the alteration of the rocks of the gondite series were formed by a combined decomposition and replacement of the gondite, spessartite-rock, or rhodonite-rock, as the case may be.

5. The alteration of manganese silicates to manganese-ores took place at the close of the Dhárwár period of folding, and hence in Archæan times.

6. The alteration took place at considerable depths, so that, taken in conjunction with the supposition that a portion of the ores are merely compressed manganese-oxide sediments, workable manganese-ores may be expected to extend in some places to as great a depth as the rocks of the gondite series.

7. The alteration was due to the attack on the manganese-silicate-rocks by waters containing either carbon dioxide or sulphuric acid, more probably the former: and also oxygen.

8. The carbon dioxide may have been a portion of that liberated in the conversion of original impure calcareous sediments into the quartz-pyroxene-gneisses of this area; and the oxygen a portion of that liberated in the conversion of original impure manganiferous sediments into the manganese-silicate-rocks.

9. A small proportion of softish and more or less porous ore has been formed since the rocks of the gondite series were exposed at the surface, and is probably still being formed.

CHAPTER XVIII.

GEOLOGY—*continued.*

Manganese in the Purána, Palæozoic, and Mesozoic Formations.

Manganese in the Purána formations—In the Gondwánas—In the Lias—In the Lametas—In the Deccan Trap.

Manganese in the Purána Formations.

Manganese has been found in small quantities only in the rock groups classed as the Purána formations. In a few cases it may have been introduced into the rock in which it occurs at the time of deposition of that rock; but in the majority of cases the manganese-ores found in these formations are of secondary origin and have been formed by the percolation of manganiferous waters whilst the rocks lay at the surface, with the infilling of cavities and cracks, or the superficial replacement of rock.

Manganese in the Kaládgi formation.

The writings of Newbold and Aytoun indicate the presence, in the limestones and quartzites of the Kaládgi series of the Belgaum and Bijapur districts, of numerous veins of manganese-ore (see pages 633 and 640). But Foote referring to the Bijapur district states his inability to find these numerous occurrences of manganese-ore in the Kaládgi rocks (page 641); hence it must be regarded as doubtful if manganese-ores occur in this formation, except perhaps very rarely.

Manganese in the Bijáwar formation.

Several occurrences of manganese-ores have been found in the rocks of the Bijáwar formation, apart from those that are obviously the result of replacement or impregnation at the surface outcrops. Thus at Sontulai in the Hoshangábád district there is an occurrence of what seems, although it is not properly exposed, to be a bed of manganese-ore (an inferior wad) intercalated between some quartzose and brecciate rocks that are apparently of Bijáwar age. It is not certain, however, that this is a true bed formed at the time of deposition of the enclosing rocks; for this body of manganese-ore may equally have been the result of the replacement, along a line of porosity or brecciation, of the pre-existing Bijáwar rocks (page 802). Unfortunately the occurrence is of no economic importance, so that it has not been opened up. A specimen of psilomelane brought from Behat in the Gwalior State came in all probability from this formation.

Manganese in the Vindhyan formation.

No certain evidence of the existence of contemporaneously-deposited manganese-ore in the rocks of the Vindhyan formation has yet been obtained. At Bunkuta near Gohugáon in the Nimár district, Central Provinces (see page 978), however, I have found small amounts of pyrolusite formed at the surface by the replacement of shales of Vindhyan age. Mr. Datta has found manganiferous hematite of possible Vindhyan age in Rewah (page 690).

Since this was sent to the press an occurrence of manganese-ore in the Lower Bhander Sandstone division of the Vindhyans has been discovered in Bhopal, near Konugáon village, which is 2 miles west of the town of Bhopal. In the sandstone are numerous bands of conglomerate, and in this and the sandstone psilomelane occurs in the form of irregular patches. It also occurs as dendroid films in the sandstone and, to a small extent, as a cementing material in the conglomerate. I am not aware if any of this manganese-ore is considered to have been deposited contemporaneously with the enclosing rock or whether it has all been secondarily introduced (see page 672).

Manganese in the Krol formation.

The occurrence mentioned by Marcadieu of crystals of marcellin (braunite) in a manganiferous and ferruginous limestone, near Dharmsála in Kángra, probably refers to an occurrence of manganese in the Krol formation.

Manganese in the Gondwánas.

Ironstone shales.

Manganese in the form of impregnations and stains and even nodules has been several times recorded in the various Gondwána formations. Thus in the Ironstone Shale group in the Burdwan district the iron-ore is constantly manganiferous, containing about $1\frac{1}{2}$ to $2\frac{1}{2}$ per cent. of this element (see page 615). In the Kámthi group nodules of psilomelane have been found in clays at Malágarh Hill in the Wun district (see page 979), whilst oxide of manganese is doubtfully recorded as occurring in sandstone of this formation at Silewáda in the Nágpur district[1]. In the Jabalpur division of the Gondwánas, psilomelane has been found in the form of nodules in clay in South Rewah (see page 690).

Kámthi group.

Jabalpur group.

[1] W. T. Blanford, *Mem. G.S.I.*, *IX*, p. 17, (1872).

Manganese in the Lias.

An occurrence is mentioned on page 613 of manganese-ore in a metalliferous vein traversing the Liassic rocks of Baluchistán at Shekhrán in Jhálawán.

Manganese in the Lametas.

In the Dhár Forest and Indore State, Central India, and in the Nimár district in the Central Provinces, the sandstones and conglomerates of the Lameta formation rest on a peneplain of Bijáwar, and metamorphic and crystalline, rocks. The former (Bijáwars) appear to have undergone a sort of lateritization in pre-Lameta times on lines analogous to the process by which the post-trappean laterites have been formed. This pseudo-laterite has been designated ' porous breccia ' by Mr. Vredenburg, and is composed of angular fragments of quartz, hornstone, quartzite, etc., set in a soft porous, loamy, matrix. The lowest Lameta beds probably consist of this porous breccia rearranged by water, so that it is often impossible to decide where the latter ends and the Lametas begin. The argillaceous-sandy matrix of this breccia is often replaced by manganese oxides (pyrolusite or psilomelane) so as to yield a breccia of angular fragments of white quartz set in a black matrix of manganese oxide.

The Lameta sandstones and conglomerates, where porous, have also often been impregnated by oxides of manganese, and where the sand grains and pebbles were originally set in an argillaceous matrix, the latter has often been replaced by psilomelane. No cases have yet been found of undoubted original manganese oxide in the Lameta rocks, except perhaps in the re-arranged manganiferous breccias sometimes forming the base of this formation; for they may have been rendered manganiferous either before or after the deposition of the Lametas. The ultimate source of the manganese that has brought about the impregnation and replacement of Lameta rocks is probably to be looked for in the metamorphic and crystalline rocks in the areas in which these rocks occur. For even if there are no manganese-silicate minerals, properly so called, in these rocks, the ferro-magnesian silicates always contain small quantities of this element. As to when the Lametas and porous breccias became impregnated with manganese oxide it is impossible to speak with certainty, but it seems likely that this took place in pre-Trappean times, when the metamorphic and crystalline rocks were uncovered and freely exposed to the action of meteoric waters. For details of

the occurrences of manganese in the Lametas and porous breccias see the accounts given under the headings of the States and districts of Dhár, Indore, and Nimár.

Manganese in the Deccan Trap.

It is probable that small quantities of manganese are fairly uniformly distributed through the lavas of this formation, these rocks being usually basic. No analyses of these lavas have, however, ever been published, so that it is not possible to say what this quantity will average ; but probably, as is usual in basalts and dolerites, only a few tenths of one per cent. Manganese-ores have been reported to occur in the districts of Amráoti, Belgaum, Dhárwár, Ratnagiri, and Sátára, but nothing further has been heard of any of these ores except those of the Sátára district. At Mahábaleshwar in this district, where the Deccan Trap formation reaches almost its highest elevation above sea-level, there are several occurrences of concretionary or nodular psilomelane, usually in a reddish clayey soil. The interesting feature of this occurrence is that the higher parts of the Mahábaleshwar plateau are covered with laterite, in which I was not able to find a trace of visible manganese oxide, the ores always occurring in the above-mentioned soil where it overlies the decomposed trap at the edges of the laterite cap. From the fact that the manganese-ores are sometimes found to contain remains of substances probably once contained in the trap it is probable that the concretions of manganese-ore, and the soil in which they occur, have been formed by the decomposition *in situ* of the trap rocks with the concentration of the manganese. Since, however, the laterite covering most of the higher parts of the plateau must also have been derived from the trap rocks by their chemical alteration, in a way that does not matter here, and since, as already mentioned, this laterite seems to be free from manganese, it is evident that a considerable amount of manganese must have been removed in solution from the trap rock from which the laterite has been produced. It may be that this manganese has also found a resting place in the soil resting on the decomposed surface of the trap. If this be the case then the manganese concretions in this soil may have derived their manganese from two distinct sources, namely (1) from the rocks by the decomposition of which the soil has been produced, and (2) from the masses of rock from which the laterite of the higher parts of the plateau has been formed. For further details about these occurrences of ore, see the account of the Sátára district (pages 661—668).

CHAPTER XIX.

GEOLOGY—*continued.*

Manganese in Laterite.

General—Low-level laterite—High-level laterite—Theories as to origin of high-level laterite—The Yeruli laterite—Lateritic manganese-ores—Lateritoid—The Talevádi occurrence—Jabalpur and Goa—List of localities—Economic value—Sandur—Distribution—Structure and working of—Mineral composition—Chemical composition.

General.

In many parts of India the geology is obscured by an overlying covering or cap of a curious rock characteristic of tropical climes. This rock consists essentially of a mixture of hydrated oxides of iron and alumina, with often a considerable percentage of titania. It is the rock known to Indian geologists as *laterite*. This word and its latin equivalent, *lateritis*, both meaning literally *brick-stone*, were invented by F. Buchanan, F.R.S., being derived from the Latin word *later*, a brick, in allusion to the custom of cutting this rock into the form of bricks for building purposes; this is on the analogy of several South Indian vernacular names also meaning brick-stone.

Origin of the term.

Much attention has been devoted to the study of this rock by Indian geologists, and it is evident from their writings, that there are several varieties. Nevertheless, they can all be classed into two main divisions. These two divisions are the *low-level laterite* and the *high-level laterite*: and it was to the low-level varieties of the Malabar coast that the term laterite was first applied by Buchanan, the extension of the term to include the high-level varieties being due to subsequent writers. This classification depends solely on the elevation at which the rock is found and is quite independent of its origin. Nevertheless, it so happens that the larger proportion of the low-level laterite is partly of detrital origin, and the larger proportion of the high-level laterite of non-detrital origin.

Division into low and high-level laterites.

Low-level Laterite.

The *low-level laterite* is found mainly in the low-lying coastal region on the east and west sides of the Peninsula. Perhaps the larger proportion of low-level laterite is of detrital origin and formed by the mechanical

[1] 'A Journey from Madras through the countries of Mysore, Canara, and Malabar,' II, p. 441. London, (1807).

disintegration and transportation of laterite from higher levels by the agency of water, to be deposited at lower levels as low-level laterite. As a consequence of its mode of formation, materials derived from the mechanical disintegration of other rocks than laterite get mixed with the detrital lateritic materials in the formation of low-level laterite. Hence, low-level laterite may contain many other substances besides those mentioned above as characteristic of laterite, and of these extraneous substances fragments of quartz are perhaps the commonest; in any case the low-level laterite on analysis would usually be found to contain a considerable amount of silica, whilst the true high-level laterites are usually comparatively free from silica, either free or combined. The whole is cemented together by segregative and chemical changes taking place in the ferruginous materials of the deposit, probably with the addition of a certain amount of ferric oxide deposited by percolating waters. The best account of low-level laterite that has been published is contained in P. Lake's paper on the geology of South Malabar[1]. From this it appears that there is a considerable amount of low-level laterite of non-detrital origin, formed, according to Lake, by the decomposition *in situ* of the underlying gneiss with a certain amount of rearrangement by rain, etc. No account of the laterite of Goa seems to have been published; but I have recently been able to examine it in several places, and think that practically all that I saw was of non-detrital origin and formed at least in part by the replacement of the underlying rocks. In some places it is free from visible manganese-ore, in others it contains spots and patches of manganese-oxide of no value, whilst at quite a number of localities it is highly manganiferous and worked as a source of manganese-ore. The laterite seemed very similar to the high-level laterite of Talevádi in Belgaum.

Manganese-ore in low-level laterite.

High-level Laterite.

The *high-level laterite* is found best developed on the plateau known as the Deccan, and further north in the Central Provinces and Central India. It seldom occurs at levels lower than 2,000 feet and never at elevations greater than about 7,000 feet[2]. A small portion of it is

[1] *Mem. Geol. Surv. Ind.*, XXIV, pp. 217-233, (1891).

[2] This figure is given on the assumption that true laterite exists in the Nilgiri Hills and Palni Hills. If, however, Medlicott and Blanford are correct in their statement that no true laterite occurs in these places, then the upper limit must be given as about 5,000 feet. Since this was written I have been able to visit the Nilgiris. I found the surface rocks to be—where not the gneisses of the charnockite series—lithomarges and clays of various colours, sometimes with associated ochres. Where I happened to go laterite was rare; but in one or two places I found rocks to which it seemed to me this term could fairly be applied.

of detrital origin, having been formed by the denudation and reconsolidation of the typical rock; but there is no need to consider this detrital variety of high-level laterite here, except to say that it is often lithologically indistinguishable from the true low-level laterites.

South Indian variety of high-level laterite.

The origin of the high-level laterites is a much debated question, concerning which many hypotheses have been advanced. This divergence of opinion is partly due to the fact that this rock is eminently susceptible of segregative changes, which produce a constant rearrangement of its constituents with the obliteration of all original structures; and partly due to what seems to be a fact, namely that two distinct types of rock have been designated by the term 'high-level laterite'. With regard to one of these Medlicott and Blanford remark [1]:—

'ferruginous clays, with but little of the true character of laterite, and due solely to the decomposition of gneissic rocks, have been occasionally described under the name. Such is certainly the case with the Nilgiris, one of the localities mentioned by several geologists. No well-authenticated occurrence of laterite is known at an elevation exceeding 5,000 feet above the sea'.

Dr. Holland [2], however, whilst aware of this passage, prefers to regard this rock as laterite. Such laterite, as might have been anticipated from its mode of derivation, often contains a considerable amount of silica, both free and combined. It seems to prevail in the areas occupied by the gneissose and crystalline rocks in the southern parts of the Peninsula, and often preserves the original structures of the underlying rock, pisolitic or concretionary structures being rare [3].

The Deccan variety of high-level laterite.

The second type of high-level laterite is that which occurs in the form of horizontal caps, resting usually on rocks of the Deccan Trap formation, but not infrequently on older rocks, especially the Dhárwárs. Those patches not actually on the Deccan Trap are usually situated near, but sometimes at great distances from, the present edge of this formation. This type of laterite does not show any structures that can be compared with corresponding structures in the underlying rock, and is not infrequently markedly pisolitic. The impression conveyed by the appearance of the often vertical scarps of this rock, particularly when the underlying rock is trap, is that there is not a gradual downward passage from completely-formed laterite into

1 'Manual of the Geology of India' (1879), p. 356.

2 *Geol. Mag.*, Dec. IV, Vol. X, p. 63, (1903).

3 I did not myself happen to notice any laterite in the Nilgiris that preserved the original structure of the gneissic rocks. The materials that did show this were the ferruginous clays (and lithomarges) referred to by Medlicott and Blanford.

the fresh underlying rock, with an intermediate stage of rock in a state of partial decomposition; but that the laterite is a distinct formation resting on the underlying rock with no necessary connection between the two. This is the type of laterite that is often so aluminous as to be *bauxite*. It is also very free from siliceous matter, either free or combined. The best account of the structure and appearance of this type of high-level laterite is the account of the laterite of Bidar by Newbold [1].

Theories as to the Origin of High-level Laterite.

The following is a list of some of the many theories that have been propounded to account for the formation of high-level laterite :—

1. H. B. Medlicott and W. T. Blanford [2] in discussing this subject consider two possible methods of derivation : namely, 'that the high-level laterite is simply the result of the alteration *in situ* of various forms of rock, and especially of basalt, by the action of atmospheric changes'; and that it may be a sedimentary deposit. They conclude that in spite of the large amount of work that has been done on the subject, it is impossible to say that either of these is the true theory, as there are objections to them both.
2. F. R. Mallet [3] suggests the hypothesis that the high-level laterite may have been formed in lakes occupying shallow depressions formed on the surface of the Deccan Trap formation at the close of the period of its eruption; during the decay of vegetable matter in contact with disintegrated ferruginous rocks, iron passes into solution as ferrous carbonate; partly in streamlets on the way to the lakes, and partly after reaching them, the ferrous carbonate is subjected to oxidizing influences with the precipitation of hydrated ferric oxide; whilst a further portion may be precipitated by the action of various organisms, especially algæ, the pisolitic structure being due to deposition round a nucleus [4]. The mode of formation

[1] *Jour. As. Soc. Beng.*, XIII, pp. 989-994, (1844).
[2] 'Manual of the Geology of India', pp. 359-364, (1879).
[3] *Rec. G. S. I.*, XIV, pp. 145-148, (1881).
[4] Or to subsequent segregative action. With regard to the part that algæ may play in such a process it is interesting to note that according to G. Bertrand, *Revue Générale de Chimie*, VIII, p. 211, (1905), Jackson has described three sorts of *Crenothrix*. 'C. *Kühniana* (ou *polyspora*) qui sépare l'oxyde de fer; *C. ochracea*, qui sépare l'aluminium avec un peu de fer; et *C. manganifera*, qui sépare le manganèse'. To the original paper in *Zeitsch, Untersuch. Nanrungs-u. G. Mittel*, VII, pp. 215-221, (1904), I have not been able to refer.

on this hypothesis is thus analogous to that of the Swedish lake ores in process of formation at the present day.

3. T. H. Holland [1], writing from experience of the Southern Indian laterites, suggests that the rock is formed *in situ*, the energy necessary for the breaking up of the silicates being derived from the vital action of organisms, ordinary and special. He further explains the development of concretionary structures by suggesting that ' in compounds where a constituent is loosely held, the "crystalline affinity" by which physical molecules tend to unite and form crystals may be more energetic than the chemical affinity'.

4. E. W. Wetherell [2], writing particularly of the Bangalore and Kolar districts in Mysore, supposes that the laterite of this area is of detrital origin and was formed by the washing of the decomposed surface detritus of the surrounding elevated ground into a lake, where it got mixed with non-lateritic material only to a small extent, and was subsequently cemented by the action of segregative tendencies, due to the presence of some organism in the lake, such as one allied to Girvanella. As Mallet also allows for the washing of detritus into his lakes, this theory is only a variant of Mallet's, giving the preponderance to mechanical instead of to chemical deposition.

5. Lastly J. M. Maclaren has recently published a paper [3] in which, relying mainly on a very clear section at Talevádi in the Belgaum district, he advances the view that lateritic deposits are derived from mineralized solutions brought to the surface by capillarity, and, are essentially replacements (either mechanical or metasomatic) of soil, or of rock decomposed *in situ*, or of both ; the contents of the solutions being derived from the rocks at and near the surface.

The Laterite of the Yeruli Plateau.

Leaving out of consideration the high-level laterite deposits of the first type, of which I have had no field experience, and also passing over

1 *Geol. Mag.*, Dec. IV, Vol. X, pp. 68-69, (1903).
2 *Mem. Mysore Geol. Dep.*, III, Pt. I, pp. 24-27, (1906).
3 *Geol. Mag.*, Dec. V, Vol. III, p. 546, (1906).

for the present the question of the source of the energy necessary to bring about the decomposition of the rocks from which laterite is either proximately or ultimately derived, it seems to me that the truth lies in a combination of the various theories mentioned. In the first place, judging from my examination of the Yeruli plateau, in the Sátára district, I do not think that Maclaren's replacement theory can be by any means generally applicable. This plateau is composed of a sheet of laterite, which happens to be very aluminous. At the north-eastern edge of the most easterly of the three caps into which the laterite has been cut, there is a conglomerate bed forming the topmost layer. It is composed of pebbles of pale buffish and pinkish bauxite set in a matrix of very ferruginous laterite, almost entirely pisolitic. This conglomeratic layer is about one foot thick, and rests on a layer of solid bauxite at least 2 feet thick, of precisely similar character to the pebbles contained in the topmost layer. This bauxite bed is not continuous for any great distance, but passes horizontally into ferruginous laterite. In other parts of the plateau some of the pebbles contained in this conglomerate are composed of the ferruginous laterite. From this occurrence there seems to be no doubt that before the end of the period during which the laterite of Yeruli was being formed, there was a break in which the already-formed laterite was subjected to denudation, with the production of the pebbles referred to above. It is difficult to imagine that these pebbles were cemented into the conglomerate by the process of deposition of oxides of iron brought up from below by capillary forces stimulated by surface evaporation; for, if so, how could the underlying bauxite have escaped being impregnated with, and partly replaced by, iron oxide, apart from the difficulty of imagining the actual way in which such cementaion could have taken place? It seems to me that the only possible way of explaining the cementation of the pebbles is to suppose that it took place beneath water, such as at the bottom of a lake. After the pebbles of bauxite had been formed by the action of running water, such as in a river valley, it is easy to imagine the formation of a lake, with bauxite pebbles lying on its bottom. We can suppose that the waters entering the lake contained salts of iron in solution derived from the surrounding ferruginous basaltic rocks, and that hydrated ferric oxide was precipitated in the lake, where it formed a cement for the pebbles, the pisolitic structure of the cement being due, either to deposition in this way round a nucleus, or to concretionary action. If then this ferruginous

A bauxite-conglomerate.

The conglomerate formed beneath water, such as in a lake.

cement was formed under water in a lake (or perhaps in a marsh orbog, why should not the remainder of the lateritic layers at Yeruli, which are usually non-pisolitic, have been formed in the same way? They may have been; but that they were more probably not is indicated by the fact that there is apparently a gradual passage downwards from the laterite into the underlying rock, as will now be noticed. It so happens that a large number of pits were sunk on this plateau in former times by the natives of these parts, it is said in search of copper; but much more probably for the extraction of the iron, although for this purpose they seem to have chosen a particularly aluminous mass of laterite. One of these shafts had been cleaned up just before my visit and deepened a little. It went through 38 feet of laterite, both aluminous and ferruginous, and then passed into a soft lavender-grey rock. On account of the presence in this rock of soft white spots, resembling in size and abundance those frequently seen in the amygdaloidal earthy traps of the region, we can suppose that it was derived from such an amygdaloidal earthy trap by some method of chemical alteration. The composition of this altered rock is shown by the following partial analysis carried out by S. Sethu Rama Rau, Sub-Assistant in the Geological Survey:—

Composition.

	Mahábaleshwar.	Yeruli.
SiO_2	35·60	38·98
Al_2O_3	35·51	35·05
$Fe_2O_3 + TiO_2$	16·91	15·81
Undetermined	11·98	10·16
	100·00	100·00

The analysis shown in the first column was also made by Sethu Rama Rau, on a sample of very similar material obtained near the lake at Mahábaleshwar at its eastern end. The similarity of these two analyses is very striking.

The composition of the fresh rock is, of course, unknown; but it cannot have been very different from that of a basalt (or andesite[1]). From the analyses of andesites and basalts given on pages 250, 251, 253, and 259 of Cole's 'Aids to Practical Geology', 1898, I have extracted the following figures for the limits of composition of these rocks :—

	Andesites.	Basalts.
SiO_2	56·2—69·0	44·2—54·0
TiO_2	0·8	1·5— 3·1
Al_2O_3	14·3—16·9	9·6—18·5
Fe_2O_3 + FeO	3·7—15·2	11·6—15·4
MnO	trace — 0·5	0·3
CaO	3·2— 7·0	8·6—10·4
MgO	0·8— 4·8	3·8—10·1
K_2O	0·9— 2·9	0·7— 2·2
Na_2O	2·5— 5·0	1·1— 2·5
H_2O	0·3— 1·1	1·3— 2·5

Three specimens of the Yeruli bauxite, taken by the late Mr. L. C. H. Young (by whom I was accompanied on my visit to this locality) as duplicates of specimens collected by me, were analysed by Messrs. J.

[1] I have considered the possibility of the rock being an andesite, because there are some ash-like layers in the traps of this region. Their composition has not been investigated, but they may be as acid as andesites; and if so, it is possible, though not very probable, that some of the earthy amygdaloidal beds, also, were, when fresh, andesites rather than basalts.

and H. S. Pattinson of Newcastle-on-Tyne, on behalf of Messrs. C. H. B. Forbes & Co. of Bombay, with the following results[1] :—

	A.690	A.691	A.693
SiO_2	2·63	5·20	1·10
Al_2O_3	46·32	54·10	57·48
Fe_2O_3	19·36	6·18	4·61
TiO_2	5·60	6·50	6·55
Cr_2O_3	0·63	trace	0·13
CaO	*nil*	*nil*	*nil*
MgO	0·29	0·24	0·07
SO_2	0·07	*nil*	*nil*
P_2O_5	0·22	0·15	0·08
H_2O (combined)	24·51	27·60	29·66
Moisture	0·40	0·10	0·40
	100·03	100·07	100·08

From the foregoing analyses it is at once evident that there is a sort of progressional change in composition from that of the original basalt (or andesite), through the decomposed lavender-grey rock to that of bauxite. This change takes the form of an increase in the amounts of alumina, titania, and water, with a decrease, amounting to almost total disappearance, in the quantity of silica, lime, magnesia, and alkalies. Had an analysis been given of one of the ferruginous varieties of laterite, it would have been seen that there is an increase in the quantity of iron oxide also. In this case, as with the bauxites, it probably would have been found that manganese was absent. It can be considered almost certain that the soft lavender-grey rock, judging from its structure and composition, is an altered amygdaloidal earthy trap, but it does not necessarily follow from the analyses given above that this altered rock passes gradually into laterite. In the pit mentioned above, however, there

[1] Published by the kind permission of this firm.

seems to be some such passage. Moreover, several other cases of apparent passage of underlying rock into laterite have been noticed by previous writers, an especially clear example being the one recently figured by Mr. Maclaren (see page 384).

It is precisely with regard to the nature and reality of such passages that opinions differ. It is generally accepted that the materials composing the type of laterite now being discussed have been derived in some way from pre-existing rocks, usually basic lavas of the Deccan Trap formation. It is also generally recognized that the formation of this type of laterite involves the disappearance, probably in solution, of the silica, lime, magnesia, and alkalies, of the original rock, with the concentration of the oxides of aluminium, iron, titanium, and sometimes manganese, to form laterite; this result of general experience agreeing with the particular case of Yeruli, as illustrated by the analyses given above. But, as can be seen from pages 374-5, there are many theories as to the method by which this result may have been produced. Each of these explanations may be true as applied to some particular deposit of laterite; but in many cases a combination of them will probably be nearer the truth.

Origin of the Yeruli laterite.

In the particular case of Yeruli it seems necessary, as already explained, to adopt Mallet's explanation with regard to the uppermost layer of laterite, namely that containing pebbles of bauxite. But, because of the difficult of accounting for the alteration of the underlying rock, without hypothecating the downward percolation of mineralized solutions, of which there is no sign, this explanation cannot be extended to the whole mass of laterite. For exactly the same reason Wetherell's theory is put out of court. This leaves the theories of Holland and Maclaren. It is very difficult to say which, if either of these theories applies to the case in question. Seeing, however, that the altered lavender-grey rock intervening between the laterite and the underlying trap is shown by analysis to be particularly aluminous and thus to correspond in chemical character with the prevailing nature of the overlying laterite, I am inclined to think that the rock was decomposed *in situ* with a gradual passage into the aluminous laterite. Had the laterite been formed in accordance with Maclaren's theory, there is no reason why the aluminous laterite should have been deposited just where the underlying rock happens to be particularly aluminous. For the rocks of this area are at least as ferruginous as aluminous, and consequently the circulating solutions that formed the laterite cap by replacement of the decomposed rock would probably have deposited a more ferruginous type of laterite. Whether,

on the other hand, it is necessary to attribute this formation of laterite *in situ* to an organic agency, as suggested by Holland, instead of to the action of ordinary chemical processes due to weathering, as in the usual theory of formation by alteration *in situ* (as noticed by Medlicott and Blanford), I do not feel in a position to judge. Apart from this point, we arrive at the conclusion that the lower portion of the laterite of Yeruli was formed by the decomposition of basic lavas *in situ*, and the upper by deposition in lakes or bogs, after a period of denudation.

Necessity of considering each occurrence of laterite separately.

I have discussed this case in such detail, partly to indicate the extreme difficulty of the question of the origin of laterite, and partly to indicate that, in all probability, no one explanation will apply to all varieties of high-level laterite, and that it is necessary to consider each case separately. Perhaps, after a considerable number of cases have been so discussed, we shall be in a position to form a truer idea as to which of the various theories here considered accounts for the greater proportion of the occurrences of high-level laterite.

Lateritic Manganese-ores.

Result of formation of laterite.

But whatever the mode of formation of this high-level laterite may be, the result, already stated on page 370, is certain, namely the formation of masses of rock composed essentially of oxides of iron, aluminium, and titanium, usually associated with a large amount of combined water; the silica, lime, magnesia, and alkalies, of the rock from which the former constituents were derived having been eliminated. Up to the present I have omitted to refer to what becomes, during the formation of laterite, of the small quantities of manganese that are contained in almost all the rocks of the earth's crust. When, in the course of the decomposition of the rocks in the area where lateritization is going on, the oxides of iron and aluminium pass into solution[1], it is probable that soluble salts of manganese are also formed and dissolved; these salts being in all probability either the bicarbonate, or combinations with various organic acids such as are often found in soil where vegetable matter comes into play. As I have already noted in a paper[2] treating of the association of gibbsite

The destination of manganese when laterite is formed.

1 It is to be noticed that, even in the case of laterite formed by decomposition of rock *in situ*, the oxides of iron and aluminium must have passed into solution at least for a short while, as is evidenced by the fact that laterite seems always to have been reconsolidated throughout and chemically rearranged.

2 *Rec. G. S. I.*, XXXIV, p. 168, (1906).

with manganese-ore at Talevádi, manganese, when present in laterite, usually renders itself conspicuous by segregating into forms, as a rule black nodules or veins of psilomelane or pyrolusite, that one would without any hesitation call manganese-ore[1]. It rarely seems, except in very small quantity (or in proper manganese-ores), to become blended with the other constituents of laterite, so as to form intimate mixtures similar to those that the oxides of iron, aluminium, and titanium, so commonly form with one another. Indeed, many large masses of laterite can be found, as for example, at Mahábaleshwar and Yeruli (see page 375), that seem to be completely free from manganese. As it cannot be supposed that the rocks from which the iron and alumina of the laterite were derived contained no manganese, it is necessary to suppose that with solutions containing manganese, iron, and aluminium, a selective precipitation can take place in Nature, analogous to that by which iron and aluminium are precipitated together in the course of chemical analysis, whilst the manganese remains in solution. Nevertheless, in the two cases mentioned above (Mahábaleshwar and Yeruli), we can point to the possible destination of the missing manganese; namely the concretions of psilomelane found in the ferruginous soil resting on the Deccan Trap lavas near the edges of, but at a lower level than, the base of the laterite caps (see page 369). In some cases, however, the manganese has remained in the laterite in the form of nodular concretions set in a matrix of ferruginous laterite.

Of the many occurrences of lateritic manganese-ores that I have been able to examine, only three were in what would be called 'laterite', without any hesitation, by all geologists. These three were in the low-level laterite of Goa; in the high-level laterite of Talevádi in Belgaum; and near Gosalpur in the Jabalpur district in laterite that must, I suppose, be called 'high-level', although it is only at a level of about

Lateritoid.

[1] It was after Part II of this Memoir was sent to the press that I visited the manganese occurrences of Sandur, Mysore, Goa, and the Nilgiris. Hence I have found it necessary to modify this chapter considerably in places; should any apparent inconsistencies be detected they must be excused as due to alterations and additions made whilst this part was in the press. The statement made in the text relative to the separation of manganese from iron and aluminium still holds as regards the true high-level laterites. In the lateritoid occurrences noticed on pages 381—386, however, the separation of manganese and iron is not always so distinct. Thus I have found in Mysore manganiferous limonite with the manganese apparently uniformly distributed through the limonite so as not to be visible as a separate constituent; but it may still be stated that as a rule manganese, if present, renders itself conspicuous by segregating into veinlets and patches of some manganese-ore such as psilomelane or pyrolusite.

1,300 to 1,400 feet. The remainder occur in a rock that some geologists would probably designate 'laterite'; but others would probably object to the application of the term. The rock to which I refer has a lateritic aspect and usually consists of a cavernous mixture of various oxides of iron, chiefly hard limonite, yellow ochre, and soft hematite. When no other constituents are present, the rock often resembles typical laterite in its structures and mineral composition so closely that when detached from its rock masses it could not be distinguished from pieces of ordinary ferruginous laterite (of non-detrital origin). Fairly often, however, it contains ores of manganese, either wad, psilomelane, or pyrolusite. The iron-ores and manganese-ores are mixed with one another in very irregular manner. Veins and patches of the manganese-ores sometimes occur in the iron-ores, whilst in other places veins and patches of iron-ores occur in a mass consisting chiefly of manganese-ores. Owing to the cavernous character of the rock the limonite and psilomelane have often been able to develop marked concretionary structures, such as botryoidal or stalactitic, whilst the pyrolusite is often in small crystalline aggregates. This rock does not always consist entirely of iron and manganese-ores. It often contains patches of quartz, quartzite, slate, or phyllite. Examination with the microscope shows that these rock patches are residual pieces of rock set in a matrix of ore, and that the latter has evidently been formed by their replacement. Examination of the masses of rock in the field, especially as revealed in the workings for manganese, confirms this deduction, and shows that there is a downward passage from the lateritic mass of iron- and manganese-ore at the surface through rock containing more and more quartzite, slate, or other rock, and less and less ore, to a rock that is free from all signs of ore. The junction between the overlying lateritic mass of rock and the rock on which it rests is consequently an extremely irregular one. There is, in my opinion, no doubt that these lateritic masses have been formed by the metasomatic replacement of the quartzite, slate or phyllite, accompanied by segregative changes. And as these rocks do not usually contain more than a very small proportion of, and often no, manganese, it is evident that the manganese must have been largely brought in from outside by percolating waters, with the resultant replacement from the surface downwards of the particular rock that happened to be at the surface where the replacement took place. These lateritic replacement deposits nearly always occur as cappings to small hills, the actual rugged surface of the rock (often spotted

with lichens) being approximately horizontal. These caps do not, however, show signs that they are the remains of a horizontal sheet, for they occur at different elevations on neighbouring hills, and as noticed above have a very irregular base. And although there are doubtless many cases where such a cap has been cut into two by erosion, yet most of the occurrences suggest that they have been formed independently of other masses of this lateritic rock. On account of the limited extent of each of these masses of rock, their different elevation, their want of horizontal bases, and the numerous cases in which the rock contains residual angular fragments of other rocks, most geologists would probably prefer to consider these occurrences as distinct from the masses of typical laterite occurring in horizontal sheets, often of considerable extension, and free from included fragments of rock different in character from the laterite. For this reason I propose to refer to these occurrences under the name of *lateritoid*, to indicate their similarity to laterite. It is to be noted that, were they to be designated 'laterite', they would by their position come into the high-level laterite division. From what I have written above it is evident that my view of the origin of these masses of lateritoid and their included manganese-ores is practically identical with Maclaren's theory of the origin of laterite in general. He bases his theory particularly on the occurrence at Talevádi in Belgaum. I have visited this occurrence myself, and although the sections were no longer so good as when Maclaren went, yet I saw sufficient to make me agree with his description of the occurrence. Although the occurrence was in an area where the laterite seemed to occur as a large spread, yet I could not see any difference between the mode of occurrence of the manganese-ores here and those in the lateritoid deposits. From this it will be seen that the Talevádi occurrence may be regarded as a connecting link between the lateritoid caps containing manganese-ores and the large spreads of high-level laterite usually free from manganese-ore. I think, however, it is more closely related to the lateritoid occurrences than to the large spreads of high-level laterite in which bauxite is so often found.

The Talevádi occurrence.

In fig. 22 I have reproduced the Talevádi section given by Maclaren, and cannot do better than quote here his description of it[1]:—

'There, pits in search of manganese expose the laterite in process of formation and give sections of some 30-40 feet in depth. The bottom of a typical section

[1] *Geol. Mag.*, Dec. V, Vol. III, pp. 537, 538 (1906).

shows a white decomposed friable sandy rock which, from exposures elsewhere, is regarded as a decomposed biotite-quartz schist. This passes upward without any abrupt change through a buff sandy clay to a reddish buff, soft rock containing small indistinct ferruginous secretions and minute manganese nodules. As the surface is approached the rock gradually acquires depth of colour, while the contained manganese secretions become larger and better defined until, at the surface, they are 2 to 3 feet across with a like depth. With increase of ferruginous content, the rock becomes so hard that, at the surface, it is often necessary to use explosives to disintegrate it. A few feet below it can be cut with a spade. Through the manganese secretions there ramify veinlets of gibbsite....'

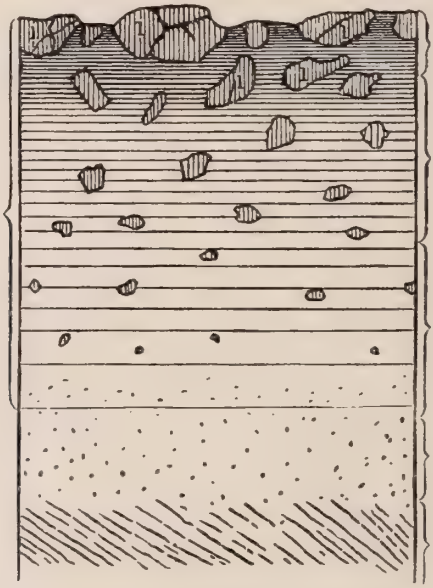


FIG. 22.—Typical Section of Laterite, Talevádi, Belgaum.
(1) Psilomelane with gibbsite veinlets.

Jabalpur and Goa.

It is interesting to note that in the Jabalpur district, the main portion of the ores has been formed by superficial replacement of slates and quartzites, and is to be classed as lateritoid; but there is also some laterite (at Gosalpur) in which pyrolusite is in places found. In Goa some of the manganese-ore is in the laterite itself; but the quarries for manganese also show that the manganese extends into the underlying Dhárwár rocks, where it has evidently been formed by the same process of superficial replacement. There seems, moreover, to be a passage upwards from the quartzite or slate through the mixture of manganese-ores or iron-ores, and residual quartzite or slate, to the overlying laterite. This overlying laterite, which is

spread over many square miles of country, has thus, although from its position low-level, probably been formed, at least in part, by replacement of the underlying rocks accompanied by the usual segregative changes. From this we see that this low-level laterite is of the same origin as the rock I have called lateritoid.

List of occurrences of lateritic manganese-ores.

In the following list I classify the occurrences of manganese-ore found in association with lateritic rocks :—

TABLE 23.

Classification of the deposits of lateritic manganese-ores.

I.—In low-level laterite :—
1. Goa.
2. Chengalput.

II.—In high-level laterite :—
(*a*) On the Deccan Trap :—
1. Bidar.
2. Bijapur (Ingleswára).
(*b*) On the Dhárwárs :—
1. Talevádi in Belgaum.

III.—In lateritoid (always on the Dhárwárs) :—
1. Bengal :—*Singhbhum.*
2. Bombay :—Dhárwár, North Kanara.
3. Central Provinces :—Jabalpur.
4. *Goa.*
5. Madras :—Bellary, *Sandur.*
6. Mysore :—*Chitaldrug, Kadur, Shimoga, Tumkur.*

IV.—In lateritic soil resting on the Deccan Trap :—
1. Sátára.

V.—Exact mode of occurrence unknown :—
1. Morbhanj.

The Talevádi occurrence should really be classified with the lateritoid. The Sátára occurrences are noticed under the heading of ' Deccan Trap ' (page 369). All the occurrences of manganese-ore in lateritoid noticed above have been made the object of prospecting operations. In all these areas the work has revealed the presence of deposits that

Economic value of the deposits.

are of value when the price of manganese is as high as it was in 1906 and 1907 ; but under ordinary circumstances most of these deposits are of too irregular occurrence and too low grade to be of much value, unless a demand for manganiferous iron-ores can be found at the same time.

The only lateritoid deposits that it may pay to work at times of low prices are those of Sandur, and some of those of Mysore (particularly Kumsi). The names given in italics show the areas from which ore has been exported.

The Sandur deposits.

The inclusion of the Sandur deposits amongst the lateritoid ones may give rise to some surprise, considering their enormous size as compared with the majority of the lateritoid deposits. It is my opinion, however, that the Sandur deposits—certainly those of the Rámandrug area, and probably those of the Kamátaru area—have been formed by the same process of superficial replacement of rocks containing but little manganese. I do not propose to go further into the mode of origin of those and other lateritoid deposits in this portion of the Memoir; but for further details I would refer the reader particularly to the accounts of the Sandur deposits given in Part IV of this Memoir, and also to the accounts of the Mysore and Jabalpur deposits.

Limitation of the term 'lateritoid'.

Some of those who may object to the deposits I have termed lateritoid being regarded as a variety of laterite may say that, if superficial replacement deposits of iron and manganese are to be called lateritoid, it will be necessary to extend the term to ores of other metals that have been formed by similar processes, such as may occur in fissure veins, near the surface. This may be avoided by restricting the term to replacement deposits of the oxides of iron, manganese, aluminium, and titanium, the four constituents characteristic of the true high-level laterite.

Distribution of manganiferous laterites, and lateritoid.

Although, as mentioned above, many masses of laterite are apparently quite free from manganese; and although the manganese when present has probably been concentrated by segregative processes, so that the manganese from a considerable area of ground has been formed into concretions distributed over a much smaller area of laterite: yet one would expect the manganiferous laterites (and lateritoid) to bear in general mode of occurrence some relation to the nature of the underlying rocks, and hence to be found in those areas where the older rocks are the most highly manganiferous. Such is found to be the case. Laterite found on the Deccan Trap, the rocks of which contain only a comparatively small amount of manganese, is, as far as is known, fairly free from any manganese-ores, the Bidar occurrence being the most notable exception; whilst laterite and lateritoid found on the outcrops of rocks

of the Dhárwár series, which is the manganese-ore bearing series of India *par excellence*, is often very rich in this mineral.

The similarity between deposits of manganese-ore in the true laterites, as in Goa and Belgaum, and those in lateritoid, as in Mysore, is so great, that the remaining paragraphs of this chapter can be taken as applying to both, bearing in mind that the Sandur deposits, and that of Kumsi in the Shimoga district of Mysore, are not typical of the whole.

The structure and working of the lateritic manganese-ore deposits.

Since the manganese-ores found in laterite usually take the form of boulders, nodules, and other concretions, set in a matrix of ordinary ferruginous laterite, it follows that in working them there will be a much larger proportion of waste per ton of ore extracted than in the case of solid bodies of ore, such as some of those of the Dhárwár type being worked in the Central Provinces. But this disadvantage is to a certain extent neutralized by the fact that the lateritic ores, owing to the comparative softness of the matrix in which they are set, can usually be quarried with greater ease than the massive ores of the Central Provinces. The lateritic deposits are further distinguished from those of the Dhárwár type by the fact that laterites and lateritoid, the rocks in which they occur, are only found at the surface, where they are disposed in more or less horizontal masses tending to be bed-like; these, as mentioned on a previous page, are rarely of a greater thickness than 100 feet, and usually much less. The distribution of the concretions of manganese-ore is, moveover, very irregular, so that a given mass of laterite or lateritoid may be very rich in ore at one point, and close by contain insufficient ore for the deposit to be worth working. The consequence is that the lateritic deposits are of much more uncertain character than the deposits of the bedded type, as exemplified by the Dhárwár deposits of the Central Provinces; and hence of much less value.

The mineral composition of the lateritic ores.

The manganese-ores found in laterite and lateritoid usually consist either of *psilomelane*, or of *pyrolusite*, or of mixtures of the two. With these, limonite and ochreous hematite are often intimately associated; and, when the iron-ores cannot be readily cleaned away, the manganese-ores are rendered valueless, unless a market can be found for manganiferous iron-ores containing a comparatively small amount of manganese. The *psilomelane* is often concretionary in shape, being either reniform, botryoidal, or mammillated. Sometimes it is compact and at other times cavernous. The cavities in the latter type of ore are sometimes lined with

smooth botryoidal crusts of the same mineral and at other times with radiate crusts of a mineral that has not yet been critically examined, but which is in all probability altered *manganite*[1]. The *pyrolusite* may also be either compact or cavernous, the cavities usually being lined with crystals of the same mineral. At other times the ores are indefinite soft varieties that can only be designated *wad*. There is also a hard light grey crystalline mineral found associated with the other ores, particularly in Mysore and Sandur; this has not yet been identified, and is not certainly always the same mineral. In some cases it seems to be probably *polianite*.

Of the various ores mentioned, psilomelane is undoubtedly the commonest. The nodules of this, when broken open, are frequently found to exhibit concentric structures, bearing witness to the way in which they were formed, namely by the deposition or growth of the manganese oxide in layers round a nucleus of already-deposited ore. The mixed psilomelane-wad ores of Rámandrug in Sandur are interesting because they are often laminated, the lamination being a relic of the parallel structures of the slates or phyllites by the replacement of which they have been formed. Both in these ores and in those of Mysore it seems as if the wad is first formed and afterwards passes into psilomelane. Another variety of ore, which is not common, except in Mysore, is *oolitic* and made up of numerous small rounded bodies, usually composed of psilomelane, and averaging 0·02 to 0·05 of an inch in diameter; these bodies are set in a soft brownish-black matrix, which gives a chocolate-coloured streak, and to which no definite mineralogical name can be given. Such ore is very high in iron, and a specimen of it, analysed by Mr. C. Fawcitt of Shimoga, showed 33·58 per cent. of manganese peroxide and 44·16 per cent. of ferric oxide, corresponding to 21·23 per cent. Mn and 30·91 per cent. Fe respectively. But the chief interest of this analysis, which is given in full on page 1138, lies in the large percentage of alumina, namely 13·04 per cent.; here, in fact, we seem to have a case in which the manganese has not been deposited separately from the alumina.

Pisolitic (aluminous) manganese-ores.

These lateritic ores differ greatly in quality from those obtained from the manganese-ore deposits of the Dhárwár facies in the Central Provinces and elsewhere. When the ore consists of pyrolusite the composition is fairly definite, corresponding approximately to the formula MnO_2. But when the

Chemical composition of the lateritic ores.

[1] See 'pseudomanganite' in Part I.

ore is a variety of psilomelane its composition may lie anywhere between certain fairly wide limits; for it seems that a piece of psilomelane may contain as much as 20 per cent. of iron without showing any visible difference from an ore containing only 5 per cent. of iron and a correspondingly greater amount of manganese. This leads to a great variability in the composition of the ores despatched, unless they are carefully assayed, and judiciously blended or mixed so as to keep the output up to a certain standard. The average percentage of iron in these ores is considerably higher than in the Central Provinces ores, with a correspondingly lower figure for the manganese. On the other hand, the lateritic ores, as a consequence of their mode of formation, are usually much lower in silica than the Central Provinces ores. The phosphorus also seems to be consistently lower. These features of the lateritic ores are well shown by the following figures, which should be compared with the figures for the Central Provinces and Vizagapatam ores given on pages 510 to 513 :—

TABLE 24.

Analyses of lateritic ores.

	Belgaum.[1]	Shimoga.[2]		Sandur.[1]
		Higher grade ores.	Lower grade ores.	
Manganese . .	31·2 —60·8	44 —56	30 —38	39·47 —54·39
Iron . . .	0·1 —18·4	2 —10	10 —20	5·38 —19·40
Silica . . .	0·6 — 2·5	1 — 3	2 — 6	0·43 — 1·00
Phosphorus . .	0·01 —0·12	0·015 — 0·060	0·01 — 0·6	0·016— 0·033

[1] From figures supplied by Mr. C. Aubert.
[2] From figures supplied by Mr. C. Fawcitt.

CHAPTER XX.

GEOLOGY—*concluded.*

Manganese in the Tertiary and Recent Formations.

Lateritic gravel or manganese-ore pisolites—Manganese in the Tertiary—In the post-tertiary—In recent deposits—In ponds and rivers—In deep-sea deposits—In manganiferous sands and soils—In fault-rock of various ages.

Lateritic Gravel (Manganese-ore Pisolites).

Manganese-ore pisolites.

In many areas where manganese-ore deposits occur one finds, scattered over the surface of the ground, numerous small rounded bodies of very uniform size, namely about that of a lentil or small pea. They are brownish-black in colour and, when fractured, are seen to be black inside and to consist of manganese-ore. These bodies can therefore be designated *manganese-ore pisolites*. A good example of their occurrence in considerable abundance is to be found at Kurmura in the Bhandára district. Here, on the low ground on the south side of the ore-ridge, they lie scattered in great abundance. When fractured they are found to be of two kinds.

Detrital pisolites.

Some of them are undoubtedly of detrital origin, consisting of rolled fragments of the manganese-ores occurring on the ore-ridge above. Such pisolites are, of course, very variable in character, on account of the variety of manganese-ores from which they have been formed; many of them are seen to be composed of the hard grey braunite-psilomelane mixture. The pisolites of

Concretionary pisolites.

the other sort show a concentric structure when broken and are much softer than the generality of the pisolites of detrital origin. Their streak is usually not pure black, as it would be if the material of which they are composed were almost entirely manganese oxide; but a brownish black, probably denoting the presence of a considerable proportion of oxide of iron intimately associated with the manganese oxide. In another mode of occurrence

Modes of occurrence.

these pisolites are scattered through clay, either thickly or thinly. As before these pisolites are found, when broken open, to be some detrital and some concretionary in origin. The clay in which they occur is usually either resting on or not far from a manganese-ore deposit. In the Central Provinces, the

ordinary succession, as seen in a section of a deposit being quarried in the alluvium, is an overburden of alluvial clay resting on a detrital accumulation of fragments of manganese-ore mixed with pieces of the accompanying rocks. The fragments in these detrital accumulations vary from very small dimensions up to pieces several inches in diameter, the tendency being for the fragments to increase in size as the ore *in situ* is approached. It is these detrital accumulations that are designated in various parts of this memoir as the *talus-ore deposits*. Sometimes these talus-ore deposits rest directly on the ore-body, but as often as not they are separated from the ore-body by a certain thickness of the *pisolitic gravel*. Thus at Kándri such an intervening layer of manganese-ore pisolites, about one foot thick, is to be seen in many of the pits in the talus-ore deposits. When the pisolites are broken open they are found, as before, to be some of them of detrital origin and some of concretionary origin.

Origin of the detrital pisolites.

The origin of the detrital fragments in all these different cases is easy to follow. Thus, in the case of Kurmura, the rolling of small fragments down the hillside and subsequent movement in every heavy shower of rain over the surface where they now lie is sufficient to account for their present rounded condition. It is easy, moreover, to conceive of such mechanically rounded fragments becoming enclosed in alluvial clay. In the cases in which these pisolites are found between the ore-body and the talus-ore deposits, it is necessary to suppose that first the pisolites collected on the surface of the ground in the same way as they are now found at Kurmura, and that later the talus-ores covered them up. Many of these pisolites, both detrital and concretionary, are also found between the fragments of manganese-ore composing the talus-ore deposits; as before the origin of the detrital pisolites is easy to understand.

Origin of the concretionary pisolites.

The origin of the concretionary pisolites in these different cases is not so simple. Briefly stated, however, it is probable that circulating surface waters dissolved a certain quantity of manganese from the manganese-ore bodies or their detritus and subsequently deposited this manganese wherever the conditions were favourable. All that would be necessary for this process to take place would be for the ground waters to contain either carbon dioxide or organic acids in solution. Such waters, on coming in contact with manganese-ore, would take certain quantities of manganese into solution. This might be deposited in

various ways. If the manganese were held in solution by carbon dioxide as the bicarbonate, and the carbon dioxide should be released, either by the rapid motion of the solvent waters, or by their coming within range of evaporating agencies, as they would at the surface, the manganese would, in the absence of oxidizing influences, be deposited as carbonate, only to be oxidized later; or, if subject to oxidation at the same time as the carbon dioxide was released, it would be deposited directly as oxide. Another way in which the manganese might be removed from solution is by the waters coming in contact with the atmosphere, or with air entangled between the particles of soil and rock a little below the surface. In this case, whether the carbon dioxide were released or not, the manganese salts would probably be oxidized with deposition of manganese in either the sesquioxide or peroxide form; whilst, if the solvent for the manganese were organic acids, the deposition of the manganese might easily take place if the oxidizing influences were stronger than the dissolving tendencies of the organic acids, which, indeed, might themselves be broken up under the same conditions. The manganese carbonate or oxide liberated in one of these ways would by preference deposit itself against already deposited manganese carbonate or oxide, and the tendency would be for this deposition to take place in concentric layers, any carbonate deposited becoming in all probability oxidized almost as soon as deposited. The method of deposition is thus easy to understand. The only point requiring elucidation is where did this deposition take place? The answer is supplied by two sections. One of these, seen at Mansar, is figured on page 884, and shows that pisolites of manganese oxide have been formed in the mica-schist along the junction of this rock, both with the manganese-ore *in situ*, and with the overlying talus deposits. From this it seems certain that these particular pisolites were deposited after the accumulation of these talus deposits and are probably still in process of formation; especially as the mica-schists, even in the dry weather, are wet, showing that probably the junction of the ore and schist acts as a directing influence for circulating waters. The other case was seen in the Beldongri quarry (see page 910), where mica-schist was again seen to contain numerous scattered pisolites of concretionary origin, the schist being overlain by pisolites set in a ferruginous clay, and this by a pisolitic gravel of which the separate pisolites were apparently mostly of detrital origin. Hence it is probable that a portion of the concretionary pisolites is formed in the mica-schist so often

Sections at Mansar and Beldongri.

forming the 'country' of a deposit, along narrow zones traversed by circulating surface waters. In all probability pisolites of concretionary origin are also formed directly in the interstices of the talus-ore accumulations and in any porous soils. Thus the mixed accumulations of pisolites must have often been formed by the denudation of the rock, such as mica-schist, in which the concretionary pisolites were formed, with the separation of these pisolites from their matrix, and their subsequent admixture with pisolites of detrital origin, only those detrital pisolites of approximately the same size as the average size of the concretionary pisolites being deposited by water along with the latter.

Summary of origin.

Hence, of the different occurrences of pisolites mentioned above, the ones in clay are in all probability often entirely of derivative origin, both concretionary and detrital pisolites having been washed into the clay. In the pisolitic deposits underlying the talus-ore accumulations the concretionary pisolites may have been in part rolled into the deposits along with the detrital pisolites, at the time of the formation of these deposits, and may have been in part subsequently deposited by manganiferous solutions percolating through these porous deposits. The pisolites, such as those of Kurmura, that are found lying loosely scattered on the surface of the ground, have probably all, even when concretionary in origin, been mechanically carried to their present position; for it does not seem probable that such concretions would form actually on the surface of the ground. Were such an accumulation as that of Kurmura to be now covered up by talus-ores derived from the hill above, we should get an exact parallel to the talus-ore deposits at present being worked; for the talus accumulations would be separated from the underlying rock by a layer of manganese-ore pisolites, of which a certain number would doubtless get mixed up with the fragments of ore in the talus-ore deposits.

Although all the examples quoted above are in the Central Provinces, yet such pisolitic deposits are equally common in association with the manganese-ore deposits of Vizagapatam and other parts of India, and will probably be found to be of common occurrence wherever manganese-ore deposits are found.

As an example of abundant pisolites scattered through sandy soil mention may be made of the occurrence at Gudhiári in the Ganjám district (page 1036).

Manganese in the Tertiary.

Excluding the laterite, which probably ranges in age from lower tertiary to recent, manganese-ores have been but sparingly found in the tertiary formations. In the Subáthu division of the Siwaliks in Afghánistán there is a record of a black substance that may possibly be manganese-ore, although supposed to be graphite[1]. An occurrence of manganese-ore, possibly in the Fossil-wood group in the Magwe district of Burma, is mentioned on page 669; whilst a certain occurrence in this formation of masses and nodules of ores of this mineral in the Taung-gnu district is noticed on page 671. This occurrence is of no economic importance.

Manganese in the Siwaliks.

Manganese in the Fossil-wood group.

Manganese in the Post-Tertiary.

An occurrence of manganiferous iron-ore in the post-tertiary rocks of the Hanthawadi district in Lower Burma is noticed on page 669.

Recent Deposits of Manganese.

General.

Under the influence of the various meteoric agencies, such as rain, frost, and heat, the rocks of the earth's crust are constantly being broken up. Some of the constituents of the rocks pass into solution in the surface and ground waters and are eventually deposited in ponds and lakes, as incrustations on rocks in rivers, possibly as infillings to mineral veins, and also as efflorescences on the surface of the ground. Those portions of the materials taken into solution that are not thus deposited are eventually carried to the sea in the waters of the rivers draining into it. Whilst a certain proportion of the constituents of rocks thus passes into solution and thus is disposed of, a considerable, and probably by far the larger, proportion is transported mechanically by water to be deposited in river valleys, lake basins, or the sea. The manganese contained in the various geological formations may be subjected to any of the influences mentioned above. Consequently the recent deposits of manganese-ore can be divided into four groups, as follows:—

1. Manganese taken into solution by the meteoric waters and deposited on the land areas, either in lakes, ponds, or rivers.
2. Manganese that escapes deposition on the land areas and is carried to the sea, where it gets deposited on the ocean bottoms.

[1] A. B. Wynne, *Rec. G. S. I.*, XII, p. 111, (1879).

3. Manganese that is transported mechanically and deposited on the land areas, such as in lake and river bottoms, as for example in the form of sands.
4. Manganese that is transported mechanically to the sea and there deposited.

No case of the last-named sort of recent deposit has yet been recorded within the limits of the Indian Empire. The known recent deposits of manganese-ore in the Indian Empire can thus be divided into three groups :—

1. Deposits in ponds and rivers ; and on the surfaces and in the cracks, bedding and joint planes, of rocks, as dendrites.
2. Deep-sea deposits.
3. Manganiferous sands and soils.

Deposits in Ponds and Rivers, etc.

As has already been mentioned, the rocks of the earth's crust nearly all contain manganese in smaller or larger proportions. Although the percentage of manganese in most rocks is very small, yet when such rocks are exposed at the surface and subjected to the influences of the weather this small amount of manganese often passes into solution under the solvent action of water containing either organic acids or carbon dioxide. Such water usually finds its way into the drainage system of the country. The tendency is for the manganese to be redeposited at the earliest possible opportunity. The condition for this to take place is usually that the water should be subjected to oxidizing influences, although it is sometimes deposited under reducing conditions. Rapid motion of the water, as at a waterfall or rapids, will sometimes bring about a deposition of the dissolved manganese as oxide[1]. A good example of this is to be seen in the fine exposure of crystalline limestones that occurs in the Pench river at Ghogara in the Nágpur district (see page 961). In one place the river forms a small waterfall down a cleft in the limestone, which consists partly of the brownish black manganiferous variety and partly of light-coloured varieties. The manganiferous limestone is coated with a layer of psilomelane, which has been deposited in concentric layers so as to follow all the curves into which the limestone had been previously carved by the water of the river.

Psilomelane deposited at a waterfall on the Pench.

[1] For foreign examples of this, on the Orinoco, Congo, and Nile, see G. Bertrand, *Revue Générale de Chimie*, VIII, pp. 209, 210, (1905).

This layer is usually about half an inch thick, but in places as much as one inch thick. It has an iron-black polished surface, with in places a sort of mammillated appearance. In some places there are thin layers of radiated pyrolusite in the psilomelane, and the underlying limestone contains quite a quantity of secondary pyrolusite, which is most abundant near the coating of psilomelane. This occurrence probably illustrates the following points:—

1. The waters of the Pench river contain salts of manganese in solution.
2. The dissolved manganese is most easily deposited as oxide where the water containing it comes in rapid contact with the air, namely at the waterfall.
3. This manganese oxide is deposited on the manganiferous limestones in preference to the non-manganiferous ones.

This psilomelane was undoubtedly deposited comparatively recently; for it follows all the carvings of the limestone and was therefore deposited after the river carved the limestone to its present shape. It seemed, however, as if the psilomelane was actually being denuded away by the river at the time of my visit; not, of course, by solution, but by the wearing action of the waters.

Manganese deposited in a pond near Rambha.

In a pond near Rambha in Ganjám, I found in January 1905 that the water on evaporating had left a deposit of manganese oxide on the gravelly sides of the pond, each piece of stone being so coated.

Pyrolusite at Pán Kuán.

Another interesting example is a deposit of pyrolusite found on the surface of Bijáwar limestone in a nálá at a point about three-quarters of a mile S. S. W. of the camping place in the Dhár Forest known as Pán Kuán. In one place the limestone surface had been corroded and coated with a deposit of fragments of pyrolusite cemented by calcareous tufa. Close by was a steeply sloping surface of limestone with a coating of almost pure pyrolusite, containing in places patches of dark brown crystalline calcite, and showing at the junction with the limestone a gradual passage into it, indicating that the pyrolusite was formed by the replacement of the limestone. When I saw this occurrence the nálá was quite dry; but in the rainy season it must often carry a large quantity of water. This must have taken into solution a portion of the manganese that is so widely distributed in the Lameta rocks of this area; and coming in

Photo. by H. B. W. Garrick. *Calcutta Phototype Co.*

PYROLUSITE (DARK) AND CALCAREOUS TUFA (LIGHT); FROM PAN KUÁN, DHÁR FOREST, CENTRAL INDIA.
½ NATURAL SIZE.

contact with the limestone must have given up a portion of its manganese in return for a portion of the calcium carbonate of the limestone. The above explanation is given on the supposition that the pyrolusite is of recent formation. This, however, cannot be considered as quite certain in a region where denudation has in so many places just worked its way down to the old land surface of pre-Lameta times. But even if the pyrolusite date back to this pre-Lameta time it will probably have been formed in much the same way—except as regards the source of the manganese—as if, as is almost certain, it has been deposited in recent times (see Plate 15).

Dendrites of manganese oxides.

The foregoing are examples of manganese-ores deposited recently at the surface. There may also be places at small distances beneath the surface at which the conditions are favourable for the deposition of manganese oxides from percolating waters. Thus dendritic growths of black manganese oxide are often found on the surfaces of joint and bedding planes of rocks when they are uncovered in the course of quarrying or mining operations. As would be expected this phenomenon is particularly common in manganese quarries. Thus I have seen beautiful examples at the Mansar mine on the surface of the fine-grained gneiss underlying the ore-body. Equally good examples were seen in the manganese-ore quarry at Ásalpáni II or Kárli. Here the dendrites were also on the surface of the bedding planes of the underlying rock, a fine-grained schistose quartzite. Such dendrites may also be found on the surface of rocks in almost any formation. Thus very fine examples have been found on the bedding planes of slabs of Vindhyan sandstone quarried at Panna for building purposes. Some fine specimens from this locality are exhibited in the Museum of the Geological Survey of India, the fern-like growths being as much as 22 inches in length (see Plate 4).

Manganese oxide in pleistocene mammalian remains at Allahábád.

In sinking wells for the foundations of the new railway bridge across the Ganges at Allahábád some fossil mammalian remains were found embedded in a calcareous conglomerate 80 to 100 feet below low water mark[1]. On examination it was found that these mammalian remains were impregnated with oxide of manganese[2]. This manganese oxide must have been deposited, long after the sealing

[1] *Rec. Geol. Sur. Ind.*, XXXII, p. 136, (1905).
[2] *Rec. Geol. Sur. Ind.*, XXXIII, p. 157, (1906).

up of these remains in their concrete matrix, by percolating waters, not necessarily derived from those of the present river, but more probably consisting of ground waters circulating before the Ganges happened to flow in its present channel.

In the same way stains of manganese oxide may be found in almost any rock near the surface. Thus some specimens obtained in opening up an asbestos deposit at Tumkhera Khurd in the Bhandára district were brought to the Geological Survey Office and were found to be composed of a mixture of asbestos and talc, with black stains of oxide of manganese in the fissures.

Manganese-oxide stains in asbestos from Tumkhera Khurd.

Deep-sea Deposits.

It is a well-known fact that the rivers draining off the land into the seas and oceans contain a certain amount of manganese salts in solution. The quantity, although a very small proportion of the total salts in solution, is in the aggregate so large that, if the figures given by Sir John Murray be anything like correct, the amount of dissolved manganese salts annually carried into the sea must be equivalent to about 37,000,000 tons of manganese sesquioxide, Mn_2O_3, or 26,000,000 tons of metallic manganese[1].

Before discussing the formation of the deep-sea deposits of manganese-ore I want to show that it is probable that the whole, and perhaps the larger part, of this manganese has not remained in solution in the sea-water. Murray gives the amount of manganese in river-water as equivalent to 5,703 tons of Mn_2O_3 per cubic mile[2], and the number of cubic miles of river-water entering the sea every year as 6.524[3]. Now 10,000,000 years is probably a very conservative estimate of the time during which oceans must have existed, with accompanying land areas from which rivers were draining and supplying water to the ocean to take the place of that removed by evaporation[4]. The present volume of the water in the oceans and seas of the world is given by Murray as 323,722,150 cubic miles[5] or, say, approximately 324,000,000 cubic

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[1] *Trans. Min. Geol. Inst. Ind.*, I, p. 73, (1906).

[2] *Scottish Geog. Mag.*, III, p. 77, (1887).

[3] *Op. cit.*, IV, p. 41, (1888).

[4] We can neglect the question of the permanence of the oceans; for if they have not had something like their present distribution during the whole of this time, the water occupying former oceans must have passed from old to new ocean areas on the formation of the latter.

[5] *Loc. cit.*, p. 39.

miles. If we can assume that this represents roughly the average volume of the oceans during the whole of this period of ten million years, and that the average annual amount of river-water flowing into the sea during the same time is 6,500 cubic miles, we see that the whole of the water of the ocean could have been supplied by the rivers in $\frac{324,000,000}{6,500} =$ 50,000 years approximately.

The supply of river-water is of course kept up by the evaporation of sea-water and its precipitation on the land in the form of rain. In this process the dissolved salts are of course left behind in the sea; hence, as in 10,000,000 years the rivers must have contributed the amount of water in the oceans $\frac{10,000,000}{50,000} = 200$ times over, sea-water should contain 200 times as much manganese per unit volume of water as average river-water. This means that a cubic mile of sea-water should contain manganese equivalent to $5,703 \times 200 = 1,140,600$ tons of manganese sesquioxide, supposing that all the manganese that has entered the sea during this 10,000,000 years has remained in solution in the sea-water. Now the figures given by Murray[1] for the dissolved matter in sea-water in terms of tons per cubic mile are as follows:—

	Tons per cubic mile.
Magnesium carbonate ($MgCO_3$)	438,000
Calcium carbonate ($CaCO_3$)	6,147,000
Potassium sulphate (K_2SO_4)	3,723,000
Sodium chloride ($NaCl$)	117,441,000
Magnesium chloride ($MgCl_2$)	16,419,000
Magnesium sulphate ($MgSO_4$)	6,529,000
Magnesium bromide ($MgBr_2$)	328,000
TOTAL	151,025,000

From these figures of Murray it will be seen that had all the manganese remained in solution in sea-water it would have formed 0·7% of the total salts and hence have been quite an important constituent[2]. It is of course known to be present in sea-water in small amounts; thus, according to Forchhammer, as summarized by Dittmar[3], manganese is readily detected in the residue left on re-dissolving sea-water solids in water. But the quantity is apparently so small that, as far as I know,

[1] *Op. cit.*, III, p. 77.

[2] Had we considered a period of only 1,000,000 years, the value of the Mn_2O_3, 114,060 tons per cubic mile, would still be too small to neglect, namely 0·07% of the total sea salts.

[3] Challenger Reports, Physics and Chemistry, Vol I, p. 2, (1884).

it has never been determined ; chemists seem to have considered it unnecessary to take it into account, even in analyses carried to six figures[1] The question then arises as to what has become of that portion of the manganese that should be present in the sea-water, and is not. The obvious answer is that it must have given rise to at least a portion of the manganese-ores known to occur at the bottom of the sea. For, during deep-sea exploration work, nodules of manganese-ore are frequently dredged up from the sea floor. In fact, in some places, according to Murray, the sea bottom and everything on it is coated with manganese oxide—shark's teeth, shells, corals, sponges, and other remains, both organic and inorganic, being encrusted with this substance.

The way in which the manganese is deposited, and also its source, is a matter of some doubt, and for a full discussion of this subject the reader may be referred to the excellent work of R. A. F. Penrose, Jr.[2], and to the Challenger Reports, Volume on Deep-sea Deposits, pp. 372-8, (1891), by John Murray and A. F. Renard. The various views held on each of these points can be seen from the following list[3] of the opinions of different authorities as to the mode of origin of manganese nodules :—

'1. The manganese of the nodules is chiefly derived from the decomposition of the more basic volcanic rocks and minerals with which the nodules are nearly always associated in deep-sea deposits. The manganese and iron of these rocks and minerals are at first transformed into carbonates, and subsequently into oxides, which, on depositing from solution in the watery ooze, take a concretionary form around various kinds of nuclei (Murray)[4].

2. They are formed under the reducing influence of organic matters on the sulphates of sea-water, sulphides being produced and subsequently oxidised (Buchanan).

3. They arise from the precipitation of manganese contained in the waters of submarine springs at the bottom of the ocean (Gümbel).

4. They are formed from the compounds of manganese dissolved in sea-water in the form of bicarbonates, and transformed at the surface of the sea into oxides, which are precipitated in a permanent form on the bottom of the ocean (Boussingault, Dieulafait)'.

Penrose further considers the possibilities that marine plants such as sea-weeds may segregate manganese in their tissues, this being deposited

1 Thorpe's Inorganic Chemistry, I, p. 208, (1902).
2 An. Rep. Geol. Surv. Arkansas for 1890, Vol. I, pp. 559-569.
3 Taken from the above-mentioned volume of the Chall. Rep., p. 373.
4 In a footnote at this point Renard says:—
'While admitting that a part of the manganese accumulated at the bottom of the ocean may be derived from the decomposition of volcanic rocks, in the manner described above (No. 1), it appears to me that the greater part must have been derived from the manganese in solution in the sea-water'.

on the death of the plant; and also that the precipitation may have been brought about by the action of calcareous sediments, when on the sea floor, or when passing through the water on the way to the bottom, the process being one of substitution by which calcium carbonate passes into solution with the precipitation of a corresponding amount of manganese oxide. He does not, however, regard either of these, or any other theories that have been advanced, as adequately explaining the formation of these submarine manganese-ores.

I do not intend to discuss here the various theories outlined above; but I will give what seems to me a fairly satisfactory explanation, for the consideration of those who have had practical acquaintance with deep-sea deposits of manganese-ores. Now according to the researches of Dittmar[1], the waters of the ocean contain both dissolved oxygen and carbon dioxide. Even at the greatest depths there is a small quantity of oxygen in solution[2], though the amount is much smaller than in the surface layers. Dittmar takes the presence of this small amount of oxygen in the depths of the ocean as a proof that the water is not absolutely stagnant[3], but subject to a slow circulation. The amount of carbon dioxide in sea-water seems to be greater than that of the oxygen; but it is usually less than is required to keep all the carbonate of calcium present in sea-water in the form of bicarbonate[4]. Now calcareous sediments are of frequent occurrence on the sea-bottom, and in such cases it may be supposed that the manganese-ores contained in the sediment have at least in part been formed by the replacement method considered by Penrose. But it must be remembered that a large proportion of the sea-bottom is covered with red clay containing abundance of manganese-ores, both in the form of concretions and as incrustations on the remains of marine organisms. A certain proportion of the manganese-ore in these red clays may have been formed by the replacement by calcareous matter of the manganese salts contained in the adjacent water; for these red clays do contain a certain amount of calcareous matter, this being in the form of such corals and thick shells as either live at, or have been able to reach, the great depths at which these red clays are found, without suffering the fate of the thinner-shelled organisms of being dissolved on the way down. But the amount

1 Challenger Reports, Physics and Chemistry, I, (1884).
2 *Loc. cit.*, p. 226.
3 *Loc. cit.*, p. 225.
4 *Loc. cit.*, p. 220.

of calcareous matter thus available does not seem to be adequate to account for the deposition of all the manganese-ore; although it must be remembered that the greater the amount of replacement of calcareous matter that has taken place, the smaller will be the amount of this material now left to be dredged up. The paucity of calcareous matter in these red clays, however, is probably due not to its having been nearly all used up in precipitating manganese oxide, but to the solution on their way to the bottom of the thin-shelled or calcareous organisms that in places where the ocean is less deep give rise to calcareous oozes. Now considering the fact that there is as a rule no excess of carbon dioxide in sea-water over that required to hold all the calcium carbonate in solution in the form of bicarbonate, it seems probable that when this solution of calcium carbonate takes place corresponding amounts of oxides of manganese and iron are thrown out of solution, according, in the case of manganese, to the following equation :—

$$MnH_2(CO_3)_2 + 2CaCO_3 + 2H_2O + O = 2CaH_2(CO_3)_2 + H_2MnO_3.$$

Any such precipitated particles of hydrated peroxide of manganese and iron would gradually sink to the bottom, which they would probably reach without solution owing to the absence of free carbon dioxide; even if they suffered solution before reaching the bottom their precipitation would lead to the transference of a portion of the manganese to a lower stratum of the sea, and, if larger calcareous organisms passing this point did not bring about another precipitation of this dissolved manganese and iron, the slow circulation of the sea-water would finally bring it within reach of the sea-bottom. The falling particles, on reaching the bottom, would act as nuclei round which further portions of manganese oxide would be deposited by concretionary action: whilst if no particles actually reached the bottom in this way, but only water with manganese in solution, then the oxygen dissolved in the water would lead to the deposition of the dissolved manganese round any already-deposited portions of manganese oxide, and round other nuclei.

I have given the foregoing brief outline of a possible way in which these deep-sea deposits may have been formed, and are still forming, to show that it is not necessary to suppose that all the manganese, or even the larger portion of it, has been derived from volcanic rocks or cosmic dust, as some previous writers have imagined. It has, moreover, the advantage of accounting for the disappearance of the large amounts of manganese salts that are constantly being carried

into the sea by rivers. My ideas as to the origin of the manganese and its method of precipitation can be summed up as follows :—

Summary of origin of deep-sea nodules.

1. The manganese, although probably partly derived from cosmic dust and volcanic débris, has been mostly precipitated from solution in the sea-water, the manganese salts having been originally brought into the sea by rivers.
2. The manganese oxide, although possibly partly precipitated as a result of the action of the vital processes of organisms, both vegetable and animal, has been mainly precipitated by calcium carbonate aided by the obscure process of segregation from solution round a nucleus[1].
3. Where the sea-bottom consists largely of calcareous sediments, the precipitation may have been mainly brought about by the solution of some of this calcium carbonate with the deposition of an equivalent amount of manganese oxide owing to the presence of free oxygen.
4. Where the sea-bottom consists of red clay, it does so because the depths are there so great that the tests of thin-shelled organisms are completely dissolved by the sea-water before they reach the bottom. The calcareous matter in being dissolved deposits an equivalent amount of manganese oxide, which descends to the bottom, and there acts as a nucleus for the segregative extraction of manganese from the waters at the sea-bottom. The deposition of manganese oxide by means of calcium carbonate associated with the red clays probably also occurs to a subordinate extent, for the shells of thick-shelled organisms may reach the bottom before being entirely dissolved.

Deep-sea nodules from the Maldive Islands.

There is at least one record of the occurrence of nodules of manganese-ore in Indian waters. This is the one, noticed on page 1116, in the channels between the composite atolls in the Maldive Islands. The depths given for soundings in such channels range from 100 to 769 fathoms, so that this occurrence can hardly be regarded as a deep-sea one.

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1 Probably to be explained as due to the supersaturation of the solution as regards the substances being deposited, here oxides of manganese and iron.

Manganiferous Sands and Soils.

It might be expected that in areas where manganese-ore deposits exist, the sands and other mechanical detritus of the streams draining therefrom would often contain particles of manganese-ore. I have occasionally noticed small particles of manganese-ore in the sands of the Indian rivers, but have never specially looked for manganiferous sands. Nevertheless, it may be considered as fairly certain that such sands exist. And a black sand should not always be taken to be an iron sand, but should be tested for manganese; for if it contained this element in considerable proportion it could be taken as a good prospecting indication of the proximity of a manganese-ore deposit. The old observers, however, seem to have noticed such sands. Thus there are records of 'iron and steel sands with manganese' in the Nizám's dominions (page 989), of 'black sand' containing manganese in the Coimbatore district (page 1032), and of 'jet black sand containing iron and manganese' in the Nellore district (page 1040). Soils may also be highly manganiferous owing to the presence of numerous particles of manganese oxide scattered through the other material composing the soil. These may have found their way into the soil mechanically, or may have been deposited in it by percolating water; but in the latter case the fact that the manganese oxide had been deposited from solution would probably be easily detected by noticing that it tended to form segregations. A good example of manganiferous soil has been found in the Chitaldrug district of Mysore (see page 1125), where extensive areas are said to be covered to a depth of 2 to 3 feet with a dark manganiferous earth yielding on analysis 9 per cent. manganese. My attention was also called to some very manganiferous black soil near Kumsi in the Shimoga district of Mysore.

Manganese in Fault-rock of Various Ages.

Manganese-ore in breccias in Central India and the Central Provinces.

In the outlying portion of the Dhár State known as the Dhár Forest or Nimánpur, situated on the north bank of the Narbada river, and in the adjoining portions of the State of Indore lying to the west, as well as in the neighbouring parts of the district of Nimár lying on the south side of the same river, the rocks of the Bijáwar system are traversed by dyke-like bands of a breccia composed of angular fragments of quartz, quartzite, chert, and hornstone, set in a hornstone-like siliceous matrix. These rocks are usually known as hornstone-breccia or chert-breccia. Not only do they traverse

rocks of Bijáwar age, but also rocks of Vindhyan age, in which case they also contain fragments of Vindhyan sandstone. The age of these dykes must therefore be post-Vindhyan; and Mr. E. Vredenburg, who has made a careful study of these breccia dykes, is inclined to regard them as of Gondwána age and as having been formed at the time of great tectonic disturbance by which the Gondwána basins were faulted. In many cases the matrix of these dykes has been replaced by black manganese oxide, the result being a rock composed of the angular fragments of the breccia, usually quartz, set in a black matrix of manganese oxide. The time at which this replacement of the matrix of the breccia by manganese oxide took place is, of course, not known; but if the time of the formation of the breccias be really the end of the Gondwána period, then this replacement is probably post-Gondwána and pre-Lameta. I will not give here an account of particular occurrences. These will be found under the headings of the respective areas.

Manganese-ore in fault-rock, Bundi State.

C. A. Hacket has found veins of manganese oxide in fault-rock near Datunda in Bundi State. The age of this fault-rock is, of course, not known. But if it belong to the great boundary fault separating the Arávallis and Upper Vindhyans in this part of India, then it is post-Vindhyan in age.

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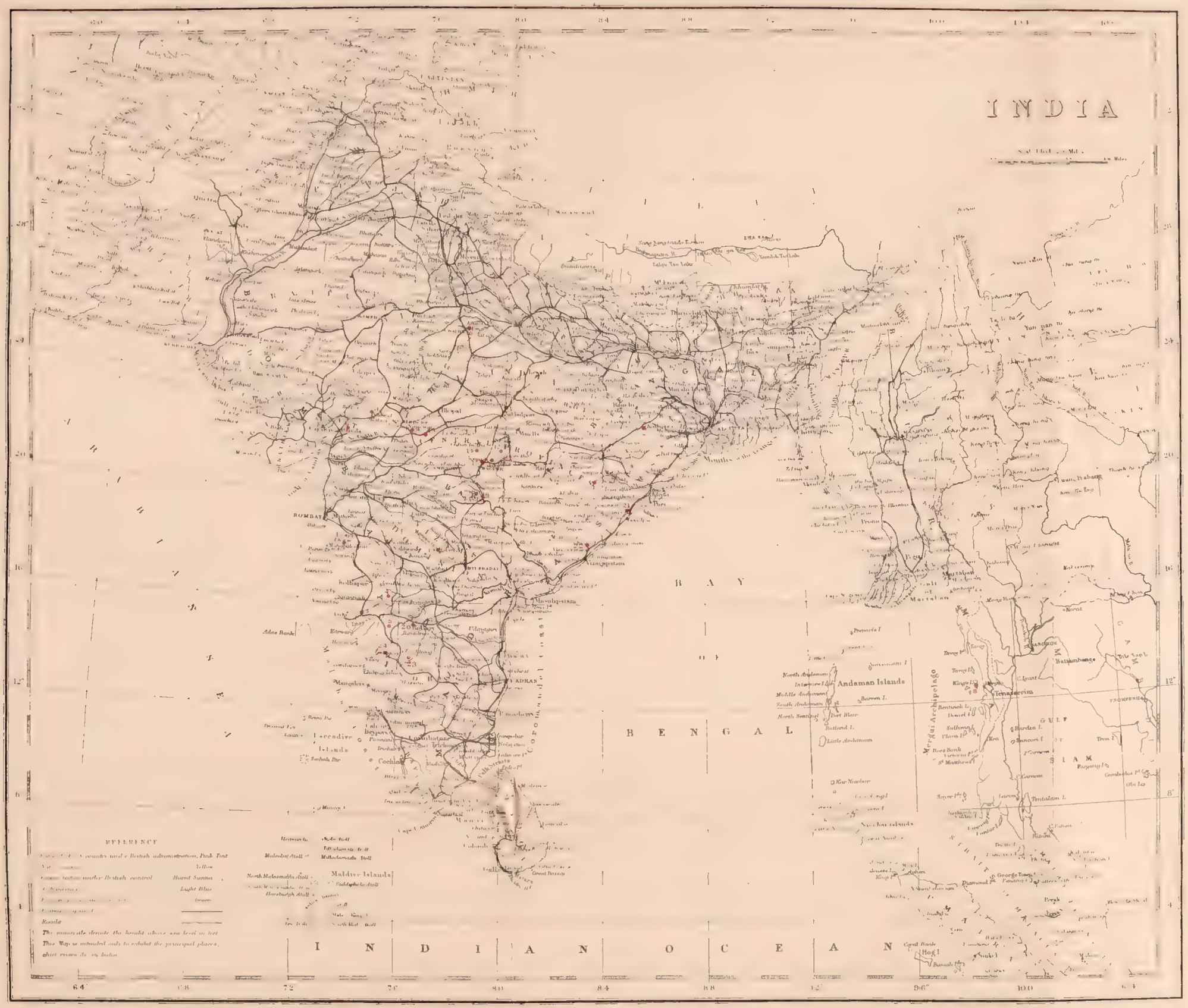

MAP OF THE CHIEF OCCURRENCES of MANGANESE-ORE IN INDIA.

INDEX TO NUMBERS.

(Manganese-ore deposits of proved economic value are found in the Districts and States underlined.)

BENGAL

1. *Kálahandi*
2. *Singhbhum*

BOMBAY

3. *Belgaum and North Kanara*
4. *Bijapur*
5. *Dhárwár (Sangli State)*
6. *Nárukot and Panch Maháls*
7. *Sátára*

BURMA

8. *Mergui*

CENTRAL INDIA

9. *Dhár and Indore*
10. *Gwalior*
11. *Jhábua*

CENTRAL PROVINCES

12. *Bálághát*
13. *Bhandára*
14. *Chhindwára*
15. *Hoshangábád*
16. *Jabalpur*
17. *Nágpur*
18. *Wun*

HAIDARABAD

19. *Bidar*

MADRAS

20. *Bellary (Sandur Hills)*
21. *Ganjám*
22. *Vizagapatam*

MYSORE

23. *Chitaldrug*
24. *Shimoga*

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THE MANGANESE-ORE DEPOSITS OF INDIA, *by* L. LEIGH FERMOR, A.R.S M., B.Sc. (London), F.G.S., *Assistant Superintendent, Geological Survey of India.*

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THE

MANGANESE-ORE DEPOSITS OF INDIA.

PART III

ECONOMICS AND MINING.

ABRIDGED CONTENTS OF PART III.

			PAGE
CHAPTER	XXI.	History of the Indian Manganese Industry . .	411
,,	XXII.	Statistics of Production of Manganese-ore in India .	431
,,	XXIII.	Labour and Costs of Production	467
,,	XXIV.	Valuation and Chemical Composition of Manganese-ores	494
,,	XXV.	Value of the Indian Manganese-ore Production .	529
,,	XXVI.	Mining or Quarrying of Manganese-ores . . .	544
,,	XXVII.	Ditto ditto *Cont* .	567
,,	XXVIII.	Uses of Manganese	581
APPENDIX TO PARTS I, II and III			605

THE

MANGANESE-ORE DEPOSITS OF INDIA

PART III

ECONOMICS AND MINING

CHAPTER XXI.

ECONOMICS & MINING

History of the Indian Manganese Industry.

The working of manganese-ores by the natives of India—Vernacular names for manganese-ore.

The fluctuations in the price of manganese-ore.

History of the modern manganese industry in India—Madras—Central Provinces—Central India—Bengal—Bombay—Mysore.

The working of manganese-ores by the natives of India.

Although, as far as I am aware, there are no ancient records on the subject, it seems probable that the existence of manganese-ores in India has been recognized by the natives of the country from time immemorial. They probably regarded them as a sort of iron-ore and made some use of them both in iron-smelting, and for colouring glasses and enamels, as well as occasionally confounding them with *surma* or antimony sulphide, then using them for colouring the eye-brows black. Thus, as noted on page 595, I found, when at Mahábaleshwar in the Western Ghâts, that the Dhávads or local iron-smelters had a separate word—*waral*—for manganese-ore; they said they used to put a certain amount of it into the charge when smelting iron. Further, an anonymous writer [1] states that there is a tradition amongst these Dhávads that the Phœnicians used to carry away manganese-ore. The use at the present day of manganiferous iron-

[1] The Indo-European Commercial Intelligence and Trade Register, I., p. 47. (1907)

ores and manganese-ores at Ghogra in the Jaba'pur district in the production of a steely iron known as *kheri* is noticed on page 595, and of the ores of Gosalpur in the same district by local glass-blowers on page 600.

Vernacular names for manganese-ore.

Uses of this sort have doubtless given rise to the several names that the ores of this mineral are at one time or another said to have possessed among the inhabitants of various parts. The following is a list :—

TABLE 25.

List of vernacular names for manganese-ore.

Name.	Locality or Language.	Authority.
Kolsá-ká-patthar	Dhárwár.	Newbold.[1]
Inganí, Injaní, Injní	Punjab.	Powell.[2]
Jugní	,,	,,
Nijní	,,	,,
Missí siyáh	,,	,,
Iddali kallu	Kanarese.	Balfour.[3]
Ukkina kallu	Sandur.	Fermor.
Sudda	Vizagapatam.	Carmichael.[4]
Surma	,,	Crozier.[5]
Waral	Mahábaleshwar.	Fermor.

When Newbold visited the manganese-ore deposit of Chik-Vadvati in the Kappatgudda range in Sangli State, somewhere about 1840[6], he went in the expectation of finding coal; for the inhabitants said there was *kolsá-ká-patthar*, or 'charcoal-stone,' at this place. Instead he found manganese-ore. He says :—

'The guides pointed out some partially obliterated excavations which the old inhabitants of the village stated to me had been made by the agents of Hyder & Tippoo.'

He suggests that the report of the existence of 'charcoal-stone' must have led the agents of these Mysorean princes to this spot, doubtless with as much disappointment as in his own case. Hence the term

1 *Jour. Roy. As. Soc.*, VII, p. 212, (1843).
2 'Punjab Products', I, pp. 25, 100, 113, (1868).
3 Cyclopædia of India, II, p. 845, 3rd edition, (1885).
4 Vizagapatam District Manual, p. 155, (1869).
5 'On the iron ores, etc., of the Madras Presidency', Madras, (1855), pp. 239, 240.
6 *Jour. Roy. As. Soc.*, VII, pp. 212—214, (1842).

kolsá-ká-patthar as applied to manganese-ore is a misnomer. Most of the Punjab terms are evidently variants of one word, and together with *missí siyáh* are the names under which the mineral is sold in the Lahore bazar; the ore so sold being the peroxide. *Missí* is the Hindustani word for a certain powder used for colouring the teeth; and the addition of the adjective *siyáh* in the case of peroxide of manganese refers of course to the black colour of this substance, in contradistinction to the ordinary greyish brown of *missí*. The use of manganese peroxide for the eyes is indicated by the application to it of the term *surma*. The true *surma*, however, is antimony sulphide, and the merchants in the Vizagapatam district who applied this term to manganese-ore said that the latter was an inferior kind. Another example of the use of the word *surma* in this sense is seen in the Central Provinces Gazetteer [1], where C. Grant refers to the occurrence of large quantities of 'surmá (sulphide of antimony)' a few miles to the east of Búrhá (the old name for Bálághát town). As no antimony sulphide has yet been found in the Bálághát district, it is to be assumed that this passage refers to the large deposit of manganese-ore situated some 3 miles north-east of Bálághát town. The term *sudda* [2] is perhaps the Telugu form of 'surma'; whilst *iddali kallu*, meaning charcoal-stone, may be regarded as the Kanarese form of 'kolsá-ká-patthar', and like it a misnomer. In the Sandur Hills I found that some of the inhabitants distinguished between *kabbane kallu* (iron stone) and *ukkina kallu* (steel stone), applying the latter to manganese-ore. The use of the term *waral* by the Dhávads of Mahábaleshwar has already been mentioned.

From the foregoing, especially the number of vernacular names, it will be seen that ores of manganese must long have been known to, and worked by, the natives of India. But for whatever purpose worked, the total amount of ore extracted at any one place can never have been very large.

History of the fluctuations in the price of manganese-ore.

Before considering the history of the discovery and working of this mineral in India by Europeans, it will be convenient to notice briefly the fluctuations in the price of manganese-ore since

[1] 1870, page 18.

[2] Mr. R. Morris, Collector of the Kistna district, tells me that *sudda* is more correctly written *suddha*, and is a Telugu word taken from the Sanskrit; it is used to designate a white pipe clay used for painting walls and also for caste marks. It is a distinct word to *surma* and hence its use to describe manganese-ore must be a mistake.

about 1845. Until this date manganese-ore was chiefly used as a decolourizer in glass-making and for the manufacture of bleaching powder. The chief sources of supply to English glass houses and chemical works were Tavistock in Devon and Launceston in Cornwall, with some ore from the Harz in Germany, and Piedmont in Italy. Prices then ruled high. Then the discovery of manganese-ore deposits in Germany caused the English mines to close. After the cessation of mining in Great Britain the price rose to £8 a ton again for an ore with 70 per cent. of peroxide. The discovery of extensive deposits in Spain then again reduced the price, till in 1865 it was only £3 for ore containing 70 per cent. peroxide, and all but three of the British and German mines were closed. The Spanish ores, being pockety, became exhausted, whilst there was a reduced supply from Germany; and at the same time a demand for manganese for steel-making sprang up, due to the start of the manufacture of ferro-manganese in 1865. As the mines then working could not supply the increased demand, manganese deposits were searched for all over the world, whilst the price of manganese-ore again went up. With the increased demand new deposits were found, but new economies also introduced. Thus whilst formerly manganese-ore was used but once in the manufacture of chlorine, it is now recovered with a loss possibly not exceeding 10 per cent. Hence, notwithstanding the increased demand, the above cause and the increased production caused a gradual fall in price to about £3-10-0 in 1881 for 70 per cent. (peroxide) ore, with 2*s.* 6*d.* per additional unit, and £3-5-0 in 1886 with 2*s.* 3*d.* per additional unit. The price of manganese-ore delivered at the works of Carnegie Bros. & Co., Ltd., at Bessemer, near Pittsburgh, Pennsylvania, United States of America, which practically ruled the United States market was as follows in 1886 :—

TABLE 26.

Price of manganese-ore per long ton in 1886.

Percentage of Mn.	Iron per unit.	Manganese per unit.
Below 44	10 cents	22 cents
44—47	11 „	23 „
47—50	11 „	24 „
50—53	11 „	25 „
Above 53	11 „	26 „

The foregoing rates are for ore with 0·17 to 0·18 per cent. phosphorus. With 0·14 to 0·17 per cent. phosphorus the price was 1 cent per unit of manganese higher; and below 0·14 per cent. phosphorus 2 cents per unit of manganese higher. With 0·18 to 0·20 per cent. phosphorus the price per unit of manganese was 1 cent lower than the foregoing prices. The analyses were made on a sample dried at 212° F., and the moisture in the sample deducted from weights. The foregoing information is taken from the section on manganese by J. D. Weeks in the Mineral Resources of the United States for 1886, page 208. It will be seen from this that in 1886 ore containing 50 per cent. manganese and only 0·10 per cent. phosphorus would have fetched 27 cents or 13½ pence per unit.

In the following table and diagram (fig. 23) are given the quotations—from the *Mining Journal*, London—for the price per unit of manganese, for the first week in January and July of each year since 1890, for the three grades into which manganese-ores are usually divided :—

TABLE 27.

Variation in the price of manganese-ore c.i.f. at United Kingdom ports.

Date.	FIRST-GRADE ORE. 50 per cent. Mn. and upwards.	SECOND-GRADE ORE. 47—50 per cent. Mn.	THIRD-GRADE ORE. 40—47 per cent. Mn.
	Pence per unit.	*Pence per unit.*	*Pence per unit.*
January 1890	18—20	16—17	14—15
July 1890	16—18	14—15	12—13
January 1891	15—17	12—14	12—14
July 1891	15—16	12—15	10—12
January 1892	14—16	12—14	9—12
July 1892	14½—15	13½—14	9—12
January 1893	14½—15	13½—14	9—12
July 1893	14—14½	11—13	9—11
January 1894	11½—12	9½—11	8—10
July 1894	10½—11½	9½—10½	8—10
January 1895	10½—11½	9—10	8—9
July 1895	10—11	9—10	7½—9
January 1896	11—13	10—12	9—11
July 1896	11—13	10—12	9—11

TABLE 27—*contd.*

Variation in the price of manganese-ore c.i.f. at United Kingdom ports—contd.

Date.	FIRST-GRADE ORE.	SECOND-GRADE ORE.	THIRD-GRADE ORE.
	50 per cent. Mn. and upwards.	47—50 per cent. Mn.	40—47 per cent. Mn.
	Pence per unit.	*Pence per unit.*	*Pence per unit.*
January 1897	11—13½	10—12	8—11
July 1897	9½—13	9—12	7½—10½
January 1898	9—12	8½—11	7½—10½
July 1898	9—12	8½—11	7½—10½
January 1899	10—12½	9—11	7½—10½
July 1899	12—14	10½—11½	8—10
January 1900	13—15	12—13	10—12
July 1900	13½—15	11½—12½	10—12
January 1901	12—14	11—12	10—11
July 1901	10½—11	9—10	—8
January 1902	9½—10½	9—9½	8—9
July 1902	9½—10½	9—9½	8—9
January 1903	10—10½	8½—9	7½—8½
July 1903	10—10½	8—9	7½—8½
January 1904	9—9½	8—9	6—8
July 1904	9—9½	8—9	6—8
January 1905	8¾—9¼	7½—8½	6—8
July 1905	9—10	8—9	6—8
January 1906	11—12	9—10½	7—9
July 1906	13—14	11—13	9—11
January 1907	15—16	14—15	13—14
July 1907	14½—15	13½—14	12—13
January 1908	10½	9½	8½
July 1908	9¼	8	7

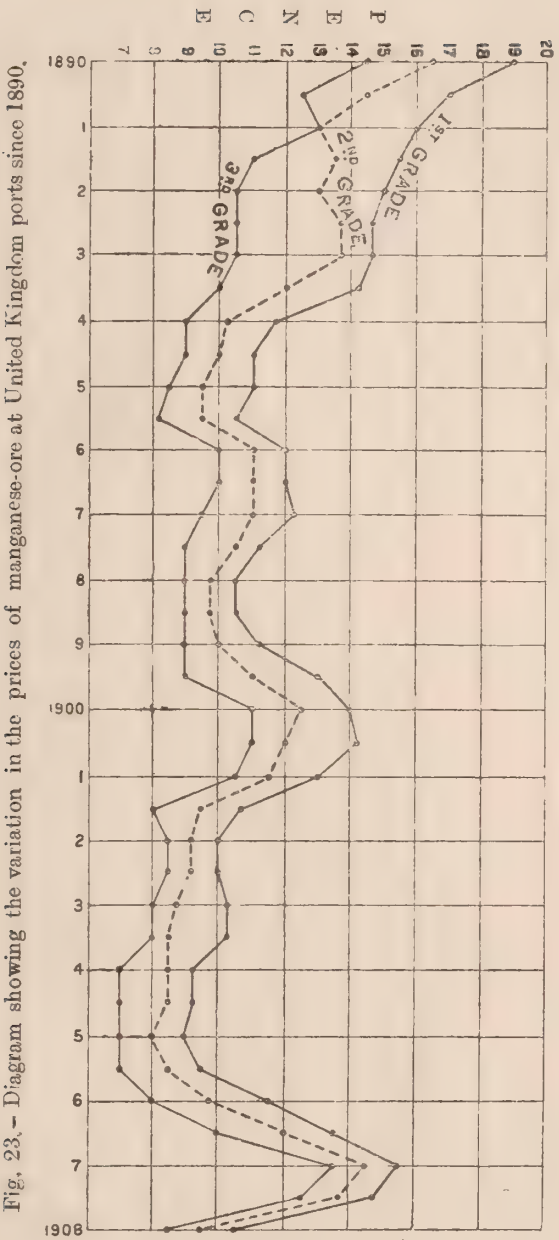

Fig. 23.—Diagram showing the variation in the prices of manganese-ore at United Kingdom ports since 1890.

Considering only first-grade ore, it will be seen that at the beginning of 1890 the mean price was 19 pence per unit, and that from this time there was a gradual decrease to a minimum of $10\frac{1}{2}$ pence in July 1895. The price then rose to $12\frac{1}{4}$ pence in January 1897; sank to $10\frac{1}{2}$ in 1898; rose to another maximum, of $14\frac{1}{2}$ pence, in July 1900; sank to 10 pence in 1902; rose slightly to $10\frac{1}{4}$ pence, in 1903; and then, at the end of 1904, declined to a minimum of $8\frac{3}{4}$ pence, the lowest point reached during the whole of the period from 1890 to 1907. Then came a continuous rise to a maximum of $15\frac{1}{2}$ pence at the end of 1906 and beginning of 1907. During 1907 the quotations have fluctuated between $15\frac{1}{2}$ and $14\frac{1}{2}$ pence, up till the beginning of September, when the prices began to fall, until by February the price for first-grade ore had sunk to 10 pence, and by August, 1908, to 9 pence. The details of the variations since the last minimum, December 3, 1904, are shown in the following diagram:—

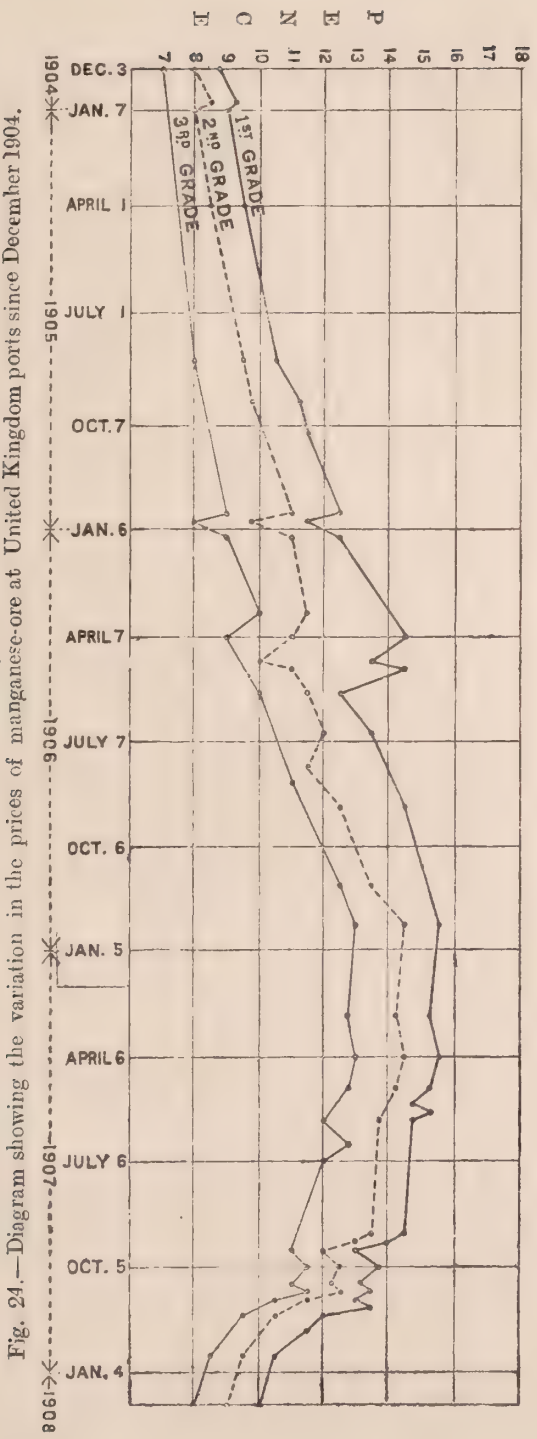

Fig. 24.—Diagram showing the variation in the prices of manganese-ore at United Kingdom ports since December 1904.

History of the Modern Manganese Industry in India.

We can now deal with the modern history of the discovery and working of manganese-ore in India.

The first definite record of the occurrence of manganese-ores in India seems to be the account given by Captain F. Jenkins [1] in 1829 of the ores found in crystalline limestone in the Pench river, and to the north of Kumári. Both these localities are in the Nágpur district, Central Provinces, the latter being doubtless the Junawáni ore-band. In the ensuing years many fresh discoveries were made in various parts of India, and the knowledge so obtained up to 1881 is summarized in Ball's Economic Geology; whilst the Mineralogy of the deposits is discussed in Mallet's Mineralogy, issued in 1887. The first attempt by a European to work any of the Indian deposits was made by Mr. C. W. McMinn, when Deputy Commissioner of Jabalpur, Central Provinces. In 1884 he sank a number of pits at Gosalpur in the Jabalpur district in order to ascertain the extent of the deposits of this locality. After the careful prospecting of the deposits of this area by Mr. P. N. Bose, then of the Geological Survey, however, the matter was dropped [2]. This practically carries us to the end of the eighties.

With the advent of the nineties the period of mere prospecting of the Indian manganese-ore deposits may be said to have ended, and the manganese industry proper, in which mining has been combined with further prospecting, to have commenced. In the following account of the development of this industry the subject is treated by provinces, in the order in which work commenced in each province. In reading this account comparison should be made with the figures and curves of prices given in the preceding portion of this chapter, so as to notice the effect of prices on this development.

Madras.

Vizagapatam: H. G. Turner and the Vizianagram Mining Co., Limited.

The existence of manganese-ores in the Vizagapatam district of Madras was known as long ago as 1852 [3]; but it was not till 1891 that Mr. H. G. Turner, previously Collector of this district, formed a syndicate to work the deposits now known as the Kodur mines. The

[1] *Asiatic Researches*, XVIII, pp. 207, 208, 210, (1833); abstract in *Gleanings in Science*, I, pp. 226, 227, (1829).

[2] *Rec. G. S. I.*, XXI, p. 71, (1888); also *op. cit.*, XXII, p. 216, (1889)

[3] A. J. Scott, *Edin. New Phil. Jour.*, LIII, pp. 278, 279.

original discovery was made, according to Mr. Turner [1], by noticing that railway contractors were breaking up the blocks of manganese-ore for ballast. The first export was of 674 tons in 1892, although this has not been recorded in the mineral statistics. In 1895 the syndicate was converted into the Vizianagram Mining Company, Ltd., with a capital of £30,600, and Messrs. Arbuthnot and Company of Madras as agents. About this time also the Garbhám deposit [2], the largest yet found in the district, was discovered, and from an output of 15,816 tons in 1895 the output of the district jumped to 56,869 in 1896, and then rose to a maximum of 92,458 tons in 1900. This corresponded with the maximum of price. Then, *pari passu* with the price, the output decreased to 53,699 tons in 1904, and from 63,679 tons in 1905 leapt up to 104,600 tons in 1906. This last increase was largely due to the fact that the sudden increase of prices during 1906 allowed of the export of ferruginous manganese-ores (manganiferous iron-ores), of which 39,186 tons, containing less than about 40 per cent. manganese, are included in the total for this year given above. The present Manager of the Vizianagram Mining Company's mines is Mr. Tom Caplen.

Gordon, Woodroffe & Co., Kovoori Basivireddy, A. S. N. & Co.

The success of the Vizianagram Mining Company naturally brought others into the field. In 1898 Messrs. Gordon, Woodroffe and Company and Kovoori Basivireddy, both of Coconada, jointly acquired various deposits in this district and extracted a certain amount of ore. After about 2 years, however, they were compelled to stop work on account of law suits with the Vizianagram Samasthanam. Messrs. A. S. N. & Co. (A. Subha Naidu), mica-mine owners of Indukurpet, Nellore, also secured some deposits—at Sivarám and other places—and worked them for one year during 1900 to 1901, and again in 1906, up till when, however, no ore had been exported.

The Madras Manganese Company and Bobbili Mining Co., Ltd.

During 1905 and 1906, the Madras Manganese Company, with Mr. S. Crawshaw of Vizianagram as manager, started work on several deposits situated within reach of Chipurupalli and Garividi stations. Some of these, such as Garividi, Devádа, and Garbhám, must be extensions of the deposits of the same name worked by the Vizianagram Mining Company. Others, such as Gadabavalsa and Lakshmipuram, are new discoveries. During 1906, fifteen deposits were worked, with an output of 4,366 tons

[1] *Jour. Iron Steel Inst.*, No. II for 1896, p. 156.
[2] *Ibid.*, p. 157.

of ore; and during 1907, 36 deposits, with an output of 21,878 tons. On the 1st January, 1908, the properties were transferred to a new company, the Bobbili Mining Co., Ltd., registered in Madras. The capital is Rs. 10,00,000 in shares of Rs. 100 each. Of this about Rs. 6,00,000 were allotted fully paid up to vendors. The managing agents are Messrs. W. A. Beardsell & Co. of Madras.

Sandur State. Messrs. A. Ghose and Jambon and Cie., and the General Sandur Mining Company, Limited.

The existence of manganese-ores in the Sandur Hills, forming the State of Sandur in the Bellary district of Madras, was recorded as long ago as 1839 by Newbold[1]; a few of the occurrences were noticed by Mr. R. Bruce Foote, in his report on the geology of the Bellary district, published in 1895 [2]. It was not, however, till 1905 that any attempt was made to ascertain the true value of the deposits, and open them up. In this year Mr. A. Ghose visited these hills on behalf of Messrs. Jambon and Cie, of Calcutta, and started to open up the Rámandrug deposit in the same year [3]. During the next two years he discovered and mapped a large number of deposits, finding some of them to be of large size. During 1905 and 1906, 1,200 and 3,208 tons of ore, respectively, were shipped, the quantity being small owing to transport difficulties. At the end of 1906 Sir Vincent Caillard joined Mr. Jambon, and in the middle of 1907 the business was converted into a company entitled The General Sandur Mining Company, Limited, with a capital of £320,000; this company has secured the monopoly of the manganese- and iron-ores of this State for 25 years (see page 99[4]).

The Central Provinces.

Up till 1899, Vizagapatam was the only district in India producing manganese-ore. In this year, however, Mr. W. H. Clark, and in 1900, Mr. Harvey Dodd, both of the Vizianagram Mining Company, Limited, prospected in the Nágpur district, following up the references given in Ball's Economic Geology.

W. H. Clark, H. Dodd, and the Central Provinces Prospecting Syndicate (Nágpur, Bálághát, and Bhándara).

To the already-known deposits of Mansar and Kodegáon they added Gumgáon, Rámdongri, Kándri, Beldongri, Sátak, and Lohdongri. The Central Provinces Prospecting Syndicate was formed to work these deposits, the members of the Syndicate being Messrs. J. H. Glass, P. Macfayden, and H. G. Turner, with Mr. Clark

1 *Mad. Jour. Lit. Sci.*, X., p. 125, (1839); XI., p. 46, (1840).
2 *Mem. G.S.I.*, XXV, pp. 98, 100, 125, 194, 195.
3 Date of first prospecting license—15th March, 1905.

as manager in India; the first prospecting license was applied for on 21st September 1899. Work was started on the Mansar deposit towards the end of 1899, and the first shipment took place in the spring of 1900, when the price of manganese-ore was 14 pence per unit. From an output of 47,257 tons [1] in 1900, the output of the Central Provinces Prospecting Syndicate from this district has risen to 93,032 tons in 1906. In September 1901 this same syndicate started work on a very large deposit near Bálághát town in the district of the same name, and has since then extended its operations to other deposits in the same district; in 1903 the syndicate started work in the Bhandára district on the Chikhla (I) and Kurmura deposits [2]. Starting with 47,257 tons in 1900 (from the Nágpur district only), the total production of this syndicate from these three districts in the Central Provinces has so increased that it reached the enormous total of 223,823 tons in 1906, this being more than $\frac{1}{6}$ of the total output of the world for that year. The syndicate has now been registered as a limited liability company.

H. D. Coggan, Jambon and Cie. and the Central India Mining Company, Limited (Nágpur and Bhandára).

The success of this syndicate soon led others to prospect the same areas in the Central Provinces for further deposits, with the resultant discovery of a large number previously unknown. In the beginning of 1902 [3] Messrs. Charles Jambon and Cie., of Calcutta, started work on several deposits discovered through the agency of Mr. H. D. Coggan, and during 1902 and 1903 opened up the following deposits in the Nágpur district:—Sátak, Parsoda, Mándri, Mánegáon, Waregáon, Kácharwáhi, and Páli. The output for the first year, 1902, was 15,423 tons. In January 1904 a company styled The Central India Manganese Company, Limited, was formed to continue the work of Jambon and Cie, Messrs. Killick, Nixon & Co., of Bombay, being the agents and Mr. Coggan continuing as general manager. The nominal capital of this company is Rs. 4,00,000, of which 2 lakhs were paid to the vendors and 1 lakh to the promoter's syndicate. In 1905 this company started to open up various properties in the Bhandára district, namely Kosumbah, Sukli, Hatora, and Miragpur. The output of this company for 1906 was 83,964 tons.

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1 This is the figure given me by the manager of the C. P. P. S. The figure returned in the mineral statistics is 35,356 tons.

2 Several of the Bhandára deposits, namely Sitapathur, Miragpur, Kurmura, Chikhla I, Sitasáongi, and Asalpani I, were discovered by Mr P. N. Datta, of the Geological Survey, in 1893-94; but the results were not made public.

3 Date of first application for a prospecting license—2nd December, 1901.

A. M. Gow Smith and the Indian Manganese Company, Limited (Nágpur and Chhindwára).

In 1902, the late Mr. A. M. Gow Smith, on coming to the Central Provinces to prospect for coal in the Chhindwára district, was led by the active export of manganese-ore taking place from Nágpur and Kámthi to prospect for this mineral as well. He took up the Kodegáon[1] deposit in the Nágpur district, rejected by the Central Provinces Prospecting Syndicate on account of the small size of its outcrop, compared with the very fine deposits they had secured in other parts of the district; and continuing into the Chhindwára district, discovered several previously unknown deposits[2], some of them, especially Kachi Dhána, Sitapár, and Gowári Warhona, being very fine deposits. The Kodegáon deposits were opened up by a syndicate styled Messrs. Gow Smith, Dundas Whiffin, & Co., and some 8,000 tons despatched during 1903. After a report by Mr. H. Kilburn Scott in 1903 a limited company designated The Indian Manganese Company, Limited, was formed to work Gow Smith's deposits. The capital of the company is £50,000. of which only 39,000 £1 shares have been issued, the amount paid up being £35,400; the amount paid for the acquisition of the mining property and rights was £25,000. Owing to the distance of the Chhindwára properties from the railway Kodegáon was the only one of this company's deposits worked up to the end of 1905. During 1906, however, under the stimulus of higher prices, Kachi Dhána, Sitapár, and Gowári Warhona, in the Chhindwára district, were also opened up, the ore of the two former properties being carted to Chhindwára, and that of the last-named to Nágpur. The output from the deposits of this company in 1906 was 16,543 tons. The mines manager is Mr. H. M. Hance, and the English agents of the company are Messrs. Everitt & Co., of Liverpool. The Indian agents were Messrs. Shrager Bros., of Calcutta, up till the autumn of 1905, and are now Messrs. Martin & Co., of Calcutta.

Jessop & Co. (Nágpur and Bhandára).

In addition to those already mentioned, there are several other firms and individuals working in the Central Provinces, though on a less important scale. Messrs. Jessop and Co. of Calcutta own deposits at Guguldoho and Bhandárbori in the Nágpur district, and Pachárá in the Bhandára district. The Nágpur deposits were

1 Date of first application for a prospecting license—6th January, 1902.

2 Mr. P. N. Datta of the Geological Survey discovered Kachi Dhána and indications of Gowári Warhona in the field season of 1893-94; but the discovery had not been made public.

opened up in 1903 [1], but no ore was despatched up till 1906, on account of the low prices previously obtaining. In this year the output from these two deposits was 4,721 tons [2], whilst 1,300 tons were obtained from the Pachára deposit during 1905 and 1906.

Cooverjee Bhoja and the Madhu Lall Doogar Mining Syndicate (Nágpur).

In 1903, Mr. Cooverjee Bhoja of Calcutta secured prospecting licenses [3] over the Mándvi Bir, Junawáni, Junapáni, and Borda, deposits in the Nágpur district, and opened them up a little, without despatching any ore. As the result of various reports on these and other properties held by Cooverjee Bhoj , it seems to have been decided that they could not be worked under the economic conditions prevailing up to 1905. In 1906, however, a syndicate known as the Madhu Lall Doogar Mining Syndicate was formed to work the various deposits held by Cooverjee Bhoja. And under the influence of the enhanced prices of this year a beginning in the export of ore was made in March 1906, the quantity despatched up to the end of the year being 4,258 tons. Another syndicate holding deposits in the Nágpur district is the Bansi Lall Mining Syndicate, concerning which, however, I have no details.

The Bansi Lall Mining Syndicate (Nágpur).

Messrs. P. C. Dutt and Burn & Co., the Carnegie Steel Company, and Tata, Sons & Co. (Bálághát).

During 1904, Mr. P. C. Dutt [4] of Jabalpur acquired rights over the Samnapur-Ukua-Gudma ore-band [5] in the Bálághát district. Later he was joined by Messrs. Burn & Co. of Calcutta in his mining enterprises, and together they secured several other deposits in the same district during 1905 and 1906. During 1907 Messrs. Dutt and Burn & Co. have disposed of most of their manganese properties. The Samnapur-Ukua-Gudma band has been sold to the Carnegie Steel Company of Pittsburg, United States of America, represented in India by Mr. J. Kellerschon of Nágpur, the purchase price being, I believe, £12,000. Of the remainder of their deposits Shodan Hurki (Katangjheri I), Katangjheri II, Bhui Hurki (one of the deposits of this name), Kochawáhi, Botajheri, and part of Ramrama, have been acquired by Messrs. Tata, Sons & Co. of Bombay, and are being opened up

[1] Date of first application for a prospecting license—6th August, 1902.
[2] This includes the ore extracted in 1903.
[3] Date of first application for a prospecting license—12th January, 1903.
[4] Date of first application for a prospecting license for manganese-ore—24th December, 1903, in the Jabalpur district.
[5] Originally discovered by Mr. P. N. Bose in 1888-89.

by Mr. H. C. McNeill, late of the Central Provinces Prospecting Syndicate; whilst Messrs. Dutt and Burn & Co. retain Ponia, Arjoni, Jám, and Ghondi.

Mathura Prasad. (Chhindwára).

In the Chhindwára district, in addition to the deposits held by the Indian Manganese Co., there are one or two held by Rai Sahib Mathura Prasad of Chhindwára, the best of these being Devi, discovered in 1903 [1]. A certain amount of ore has been extracted from this deposit, but it is of low grade, and, as far as I know, none has been despatched to the railhead.

D. Laxminarayan Nágpur, Bhandára, and Bálághát).

During 1906 [2] Mr. D. Laxminarayan of Kámthi commenced to open up various deposits in the Nágpur, Bhandára and Bálághát districts, some of the properties secured being the ends of already-known deposits secured by other workers who were earlier in the field. But Pársioni in Nágpur, Kárli (Asalpáni II) in Bhandára, and Góraghát, Chikmára, and Chaukhandi, in the Bálághát district, are deposits not previously opened up. Laxminarayan claims to have extracted some 36,000 tons of ore from these deposits during 1906.

Central India.

Kiddle, Reeve & Co. (Jhábua).

After the Central Provinces the next area to which attention was directed was Jhábua State in Central India. The occurrence of manganese-ores in this State seems to have been known at least as long ago as 1896. The original discoverers were apparently the local native officials who sent the mineral to the Political Agent for the Bhopáwar Agency to find out what it was. A prospecting license was eventually granted to Messrs. Kiddle, Reeve & Co. of Bombay in May 1902, and a mining lease over the Kájlidongri deposit was taken out by this firm in May 1904. The first despatch of ore was in 1903, the amount being 6,800 tons. This has increased yearly up to 50,073 tons in 1906, the ore being derived almost entirely from the Kájlidongri deposit. Several other deposits have been discovered in this State, but most of them are of little value. The manager of Kiddle, Reeve & Co.'s properties is Mr. H. J. Winch.

[1] Date of first application for a prospecting license—19th September 1903.
[2] Date of commencement of first prospecting license—16th November 1905.

Bengal.

The deposits of manganese-ores and manganiferous iron-ores situated to the south of Chaibása in Singhbhum have been known since their discovery about 1880 by V. Ball. In 1904 prospecting licenses were taken out by Messrs. Hoare, Miller & Co.[1], and Mr. C. Aubert of Jambon and Cie. [2], both of Calcutta, over portions of these areas. A considerable amount of development was undertaken without any satisfactory results, so that both these firms abandoned their rights, which have since been assumed by the Madhu Lall Doogar Mining Syndicate. During 1906 this syndicate has accumulated about 1,000 tons, but has not yet been able to despatch it to the railway on account of transport difficulties. During 1907 deposits have been discovered in other parts of Singhbhum, notably at Leda Hill, but nothing has yet been done on them. Deposits have also been recently discovered in Gangpur; one of these, Gariajhor, is of considerable value.

Hoare, Miller and Co., Jambon & Cie., & the Madhu Lall Doogar Mining Syndicate. (Singhbhum.)

Bombay.

In 1904, manganese-ores were discovered by Mr. T. B. Kantharia of Bombay at Talevádi in the Belgaum district. They were opened up by Mr. T. R. Frizoni on behalf of Messrs. Jambon & Cie. [3] and in the middle of 1905 sold to Mr. C. P. Boyce of Belgaum. Although a fair amount of ore had been extracted, none of it had got further than Mormugáo up to the end of 1907.

T. B. Kantharia, Jambon & Cie., & C. P. Boyce. (Belgaum).

Early in 1905, Mr. T. B. Kantharia, following up an occurrence noticed by the late Dr. W. T. Blanford [4], prospected the country round Sivarájpur in the Panch Maháls district of Bombay. The deposits discovered were taken up in the name of Mr. F. A. H. East [5] of Bombay and were later taken over by a company formed for the purpose, called The Shivrájpur Syndicate, Limited. The original capital was Rs. 1,00,000 in shares of Rs. 10 each. This was increased in August 1906 to Rs. 2,50,000 of which 20,000 shares had been issued at the end of this year. In February 1908 it was proposed to increase the capital to Rs. 5,00,000 by the creation of

T. B. Kantharia & the Shivrájpur Syndicate, Limited. (Panch Maháls.)

1 Date of application for first prospecting license—7th January 1904.
2 Date of application for first prospecting license—6th February 1904.
3 Date of commencement of first prospecting license—3rd May 1905.
4 *Mem. G. S. I.*, Vi, page 341, (1869).
5 Date of commencement of prospecting license—5th July 1905.

25,000 new shares of Rs. 10 each. The managing agents are Messrs. Cory Brothers and Co., Ltd., of Bombay. The first shipment of ore from Sivarájpur took place during 1906, and the total amount of ore extracted up to the end of this year was 7,286 tons.

The Bámankua Manganese Company, Limited. (Panch Mahals.)

In June 1907, a company styled 'The Bámankua Manganese Company, Limited', was floated in Bombay privately with a capital of Rs. 3,00,000, to work a deposit on Bámankua Hill, some 3 miles north of the deposit being worked by the Shivrájpur Syndicate. 2,428 tons of ore were extracted by this company up to the end of 1907.

Mysore.

W. Ainslie, T. J. Newbold, and the Mysore Geological Department.

On page 420 it is mentioned that the first definite account of the occurrence of manganese-ores in India refers to the find near Kumári in the Nágpur district of the Central Provinces, noticed by Jenkins in 1829. It is to be noticed, however, that Dr. W. Ainslie [1], in 1813, says that this metal 'it is to be presumed, is not common in India. Captain Arthur, however, informs me that he found it in Mysore, massive, in an indurated ochre, combined with oxide of iron'. Newbold [2] also referred to the occurrence of ores of manganese in this State as early as 1840, whilst manganese-ores from Bangalore were exhibited at the Madras Exhibitions of 1855 and 1857 [3]. There was no definite knowledge of the actual locality of any deposit of manganese-ore in Mysore State, however, until 1899, when Mr. H. Kelsall Slater, of the Mysore Geological Department, found some loose pieces of manganese-ore in the bed of a stream some 3 miles north-north-west of Kumsi in the Shimoga district [4]. Mr. Slater also seems to have been the first to find manganese-ores at Shankargudda, Hoshalli, Shiddarhalli, Gangur, and near Shikarpur, in the same district; and in the Kadur district, immediately to the east of Shiddarhalli [5]. In the Chitaldrug district manganese-ores seem to have been first discovered (also in 1899) by Dr. W. F. Smeeth and Mr. Sambasiva Iyer, in the Iplára Hills near Madadkere [6], and later by Mr. P. Sampat Iyengar [7] at several localities in the soft clays and lithomarges of the Chitaldrug belt of Dhárwár rocks.

[1] Mat. Med. of Hindoostan, p. 57.
[2] *Mad. Jour. Lit. Sci.*, XI, p. 45, (1840); *Jour. Roy. As. Soc.*, VII, p. 214, (1843); *Op. cit.*, VIII, p. 155, (1846).
[3] Jury Reports, 1855 & 1857.
[4] *Rec. Mysore Geol. Dept.*, IV, p. 138, (1902-03).
[5] *Op. cit.*, V, pp. 45, 54, (1903-04); VI, p. 26, (1904-05).
[6] *Op. cit.*, II, p. 167, (1898-1899); IV, pp. 160,161, (1903-04).
[7] *Op. cit.*, VI, pp. 84, 92, (1904-05).

No attempt was made to open up these deposits until the end of 1904, when Messrs. W. T. Hamilton Holmes, J. Short, and Eardley Norton, took out prospecting licenses for some blocks situated near Kumsi in the Shimoga district. In 1905 a syndicate, designated the Madras Mysore Mining Syndicate, was formed to take over these concessions. This syndicate obtained further concessions in this year. As the result of the opening up of these deposits, The Mysore Manganese Company, Limited, was formed and registered on the 9th March, 1906, with a capital of Rs. 10,00,000 divided into 10,000 shares of Rs. 100 each. Of this total Rs. 6,25,000 were paid up. In view of the fact that this company was the pioneer in the manganese industry in Mysore, it was granted a special concession. This took the form of an option over a reserved area with a radius of 13 miles from Ayanur in the Shimoga district as centre. Within this area the Mysore Manganese Company are to have the first refusal of any concessions, for a period of three years up to the end of 1909, the Mysore Darbár reserving to itself the right to refuse any licenses that appear unnecessary or undesirable. Previous to the reservation of this area other licensees had taken out licenses over an area of 29¾ square miles situated within it.

W. T. Hamilton Holmes and the Mysore Manganese Company, Limited. (Shimoga.)

On the 31st January, 1907, a new company called The New Mysore Manganese Company, Limited, was registered in London, with a capital of £150,000 in 150,000 shares of £1 each. Of these 50,000 shares were issued fully paid up to the Mysore Manganese Company, Limited, and the remainder allotted and fully paid up. The new company takes over all the mining interests and properties of the old company. It is proposed to raise a further £50,000 in the form of debentures to provide railway transport and open up the mines. The directors of the new company are nearly all interested in the Workington Iron and Steel Company, and the Moss Bay Hæmatite Iron and Steel Company of Workington; Mr. W. J. Eales of Madras is managing director and Mr. S. O. Stromquist, superintendent of the mines. During 1906 the Mysore Manganese Company raised 40,773 tons of manganese-ore and exported about 37,000 tons to Mormugáo. The distance of the chief deposit of this company, namely Kumsi, from the Southern Mahratta Railway terminus at Shimoga is 29 miles, over which distance a light steam tramway of 2-foot gauge is under construction. Of this all but 10

The New Mysore Manganese Company, Limited. (Shimoga.)

miles had been completed in September 1907. The chief deposits held by this company are those near Kumsi, Shankargudda, and Bikonhalli.

The Peninsular Minerals Company of Mysore, Limited (Tumkur and Chitaldrug).

The next company to be formed was 'The Peninsular Minerals Company of Mysore, Limited', which was registered on 3rd September 1906, with a nominal capital of Rs. 3,00,000, of which 250 shares of Rs.100 each were issued to vendors, whilst 2,000 shares of Rs. 100 each have been subscribed for, with Rs. 50 per share called up. This syndicate took over 15 prospecting licenses held by different individuals in the Tumkur and Chitaldrug districts. The chief deposits are round Kárekurchi and Hoshalli in the Tumkur district, and reached from Bánasandra Station, Southern Mahratta Railway; and at Kenkere, Kittadhalli, and Madadkere, in the Chitaldrug district. This company produced 4,126 tons of ore during 1906.

Miss A. E. Dawson and the Shimoga Manganese Company, Limited. (Shimoga and Kadur.)

Another company called 'The Shimoga Manganese Company, Limited', with a nominal capital of Rs. 10,00,000, was formed during 1907 to work various deposits secured by Miss A. E. Dawson of Bangalore. The deposits are situated round Shikarpur and Hoshalli in the Shimoga district, and in the Kadur district, just over the border of the Shimoga district to the east of Shiddarhalli. During the first half of 1907 some 4,000 tons of ore have been shipped by this company. The agents are Messrs. Schröder, Smidt & Co. of Calcutta.

Other concessionaires.

The success of the Mysore Manganese Company lead to a regular rush for manganese concessions in Mysore and as a result enormous areas have been staked out by numerous prospectors, especially in the districts of Chitaldrug, Kadur, Shimoga, and Tumkur. A large number of these concessions doubtless contain no manganese-ore, and of those that do a large number must be of practically no value. Of those concessions known to contain manganese-ore may be mentioned Sádarhalli in the Chitaldrug district, held by Mr. W. W. Coen of Hubli; Gangur and Kaginelli in the Shimoga district, and the Iplárá and Nirugudda Hills in the Chitaldrug district, held by Mr. C. N. Surya Narayana Row of Bangalore; and Sulekere in the Shimoga district, held by Mr. Subramania Moodaliar. There is also a syndicate—the Haji Prospecting Syndicate—holding concessions in the Holalkere taluk of the Chitaldrug district.

CHAPTER XXII.

ECONOMICS & MINING—*continued.*

Statistics of Production of Manganese-ore in India.

Sources of information—Detailed table of production—Deposits that have yielded over 100,000 tons—Comparison of prices with production figures—Comparison of Indian and foreign manganese-ore production—Exports of Indian manganese-ore—Distribution of Indian manganese-ore exports.

Future prospects of the manganese industry in India.

Sources of information.

In the preceding paragraphs I have had occasion to make several references to the production or output from the deposits of the different operators working manganese-ore deposits in India. It will therefore be convenient to give here the detailed figures of production of manganese-ore in India. The only figures ordinarily accessible are those given in the Annual Reports of the Chief Inspector of Mines and the Annual Reviews and Statistics of Mineral Production in India. In the case of the Chief Inspector of Mines the figures are supplied direct by the local mine operators; whilst in the case of the 'Mineral Production' the figures are obtained from the provincial governments, to whom they are supplied by the mine operators. The figures as published are not detailed, for although they show the output of each district and province, they do not show the output of each deposit. It is, however, a matter of considerable interest to know how the output is distributed among the various deposits. Hence I have obtained from the mine operators detailed figures of production, given separately for each deposit, as far as they have been kept. These are given in tables 28 to 34 on the following pages, whilst in table 36 are given the yearly totals for the producing provinces as they have appeared in the 'Mineral Production'.

It will be seen that my totals differ in many respects from those given in the 'Mineral Production'. This is due to various causes. In the first place, according to 'The Indian Mines Act, 1901', no working is officially regarded as a mine unless it has been worked to a depth of 20 feet, or extends beneath the superjacent ground. And unless a

working is a mine in the official sense of the term, the operators are not required by the Mines Act to submit figures of output and labour for that particular working. Consequently, since many manganese quarries do not reach a depth of 20 feet until a year or two after the beginning of operations, the figures of production from some workings are liable for the first year or two to escape inclusion in the 'Mineral Production'. This is not universally applicable, however, for many operators who have several deposits already officially declared to be mines, submit figures for the whole of their deposits. Another reason for the inaccuracy of the official figures of production is that some of the figures reported are not true figures of output or 'raisings', as they are often called; but of the amount of ore despatched to the port of shipment, that is of the amount of 'despatches' or 'railings'. The figures I give in the following tables are fuller than those given in the 'Mineral Production' because they include the output of several deposits not deep enough to be called mines. They are, however, only an approximation to the true output figures. For not only are there probably several small operators of whose existence I am not aware, but some of the figures are, to my knowledge, 'railings'. Thus the figures for Jhábua, which are the same as those given in the 'Mineral Production', are entirely 'despatches' or 'railings'. The reason of their return in this form is no doubt the greater convenience of the operators; and, as the deposits are not in British India, the Mines Act does not apply, and consequently no objection can be taken to the return of the figures in this form. The chief reason for the difference between the figures I give for the output of the Central Provinces, and those given in the 'Mineral Production', is a difference in the method of returning the output of the Mansar deposit in the Nágpur district. During 1900 and 1901 a large quantity of ore was quarried along the outcrop of this deposit, which lies along the top of a ridge. This ore was a considerable distance from the aërial ropeway that was constructed to tap another part of the deposit, and was therefore of no more use to the operators than if it had been left in the ground. Consequently it was not returned in the output figures for the years when it was extracted. But the subsequent construction of gravity-inclines to tap this part of the ore-bed allowed of the shipment of the whole of this ore during 1905 and 1906, and it has probably appeared in the mineral production for those years. In the figures I give, supplied by the manager of the Central Provinces Prospecting Syndicate, this ore is entered up in its right place as regards date of quarrying.

Detailed tables of production.

Table 28 gives in detail the production from each deposit in the Vizagapatam district, Madras, the district in which manganese-ore was first worked in India. In tables 30 to 33 are given the detailed output figures for the four producing districts of the Central Provinces, the area in which work next started. The fluctuations in the output from these four districts are shown graphically in fig. 25. Table 34 gives the detailed output for all the remaining districts and States, namely :—Singhbhum, Belgaum, Panch Maháls, Jhábua, Sandur, and Mysore. Table 35 summarizes the preceding tables and shows the output for the whole of India by districts and States, whilst fig. 26 immediately following this table shows graphically the growth in the manganese industry in India, as regards output.

TABLE 28.

Detailed production of the Vizagapatam district, in long tons.[1]

Year.	The Kodur Mines. (1 to 5)	Perapi (7)	Mulagám. (9)	Govinda-puram. (10)	Garbhám (11)	Gadasám (13)	Avagu-dem. (14)	Aitem-valsa. (15)	Gotnandi.	Bondapilli. (17)	Garrará-ju Chip-urupalli. (18)	Perumáli. (19)	Rámabha-drapuram. (20)	Nellimerla.	Lingala-valsa.	Madras Mangan-ese Co.[3]	Total for each year.
1892 . .	674	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	674
1893 . .	3,130	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3,130
1894 . .	11,410	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	11,410
1895 . .	15,816	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	15,816
1896 . .	26,869[2]	..	..	..	30,000[2]	..	..	..	..	..	..	..	..	..	..	..	56,869
1897 . .	23,947	..	..	..	50,520	..	..	..	..	..	..	..	..	..	..	..	74,467
1898 . .	27,800	..	..	..	34,691	..	..	389	109	..	..	..	..	..	..	..	62,980
1899 . .	29,312	..	..	..	53,315	..	2,025	..	..	..	..	..	..	..	..	..	84,652
1900 . .	28,163	3,800	120	..	56,195	..	..	..	..	200	3,500	30	..	..	..	..	92,008
1901 . .	18,210	3,100	..	..	54,163	..	..	..	..	..	980	10	10	..	..	..	76,473
1902 . .	14,748	4,563	..	..	47,544	..	..	..	..	..	1,176	..	140	..	..	..	68,171
1903 . .	15,985	1,779	..	..	43,734	..	..	..	..	..	1,403	..	173	..	..	..	63,074
1904 . .	12,065	..	..	..	41,487	..	..	..	..	..	..	..	50	..	..	..	53,602
1905 . .	14,752	4,715	..	..	40,368	..	..	..	..	..	3,844	..	110	..	..	..	63,789
1906 . .	16,048	19,226	..	1,269	44,861	1,535	12,072	1,965	..	..	4,918	2,372	496	3,135	138	4,366	111,501
Total for each deposit.	258,929	37,183	120	1,269	496,878	1,535	14,097	2,345	109	200	14,921	2,412	979	3,135	138	4,366	838,616

Grand Total Production of all deposits since the beginning of operations = 838,616 tons.

[1] Figures supplied chiefly by Mr. T. Caplen, and, for 1906, by Mr. H. B. Geeson. They relate almost entirely to the deposits leased by the Vizianagram Mining Co., Ltd., except the last column but one, which refers to the Madras Manganese Company. There may have been a small output during 1906 from deposits taken up by operators other than these two companies; but I have received no information of such.

[2] Totals not recorded separately. My division of the total 56,869 in this way is a guess.

[3] For details see table 29 below.

Since the preceding table was drawn up I have obtained information about the output of the Madras Manganese Company, which started operations on the first two of the deposits listed below in 1905, and on the remainder in 1906. It will be convenient to keep the detailed output figures for this Company separate from those previously given, which relate almost entirely to the Vizianagram Mining Company, Limited. It will be noticed that some of the deposits worked by the Madras Manganese Company have the same names as those given above. This means that this company has in these cases leased portions of the same villages as those in which the Vizianagram Mining Company is working.

TABLE 29.

Production of Madras Manganese Company (Vizagapatam district) during 1906.

Deposit.	Output [1].
	Long tons.
Devâda[2]	1,642
Garividi	754
Gadabavalsa	789
Lakshmipuram	603
Nimmalavalsa	165
Lingalavalsa	32
Sarveswarapuram	87
Vijiarámpuram	38
Bondapilli	43
Batuva	143
Viswanadhapuram	2
Challapuram	32
Garbhám	36
Rávivalsa	..
Chipurupalli	..
TOTAL	4,366

[1] Figures supplied to the Deputy Commissioner of district.
[2] Includes a certain amount of ore extracted in 1905.

TABLE 30.

Detailed production of the Bálághát district in long tons.

	1901	1902	1903	1904	1905	1906	Total for each deposit.	Total for each syndicate, etc.
Central Provinces Prospecting Syndicate [1].								
2. Thirori	..	361	..	..	..	3,088	3,449	
2. Ponia	..	..	..	..	..	4,742	4,742	
2. Jámrapáni	..	..	..	..	..	4,059	4,059	
6. Ramrama	..	..	..	..	..	6,091	6,091	
9. Bálághát	3,839	1,614	7,898	10,323	16,246	78,499	118,419	
YEARLY TOTALS	3,839	1,975	7,898	10,323	16,246	96,479	136,760	136,760
D. Laxminarayan [2].								
2. Jámrapáni	..	..	..	..	..	27½	27½	
Garraghát	..	..	..	..	..	1,753½	1,753½	
Chikmára and Chaukhandi	..	..	..	..	..	1,297½	1,297½	
Sáonri	..	..	..	..	..	339½	339½	
YEARLY TOTALS	..	..	..	..	..	3,418	3,418	3,418
P. C. Dutt and Burn & Co.								
Ukua (Samnapur, Gudma)	..	..	..	..	..	2,363	2,363	
YEARLY TOTALS	..	..	..	..	..	2,363	..	2,363
GRAND YEARLY TOTALS	3,839	1,975	7,898	10,323	16,246	102,260	142,541	142,541

Grand total for the whole district, 1901—1906 = 142,541 tons.

[1] Supplied by Mr. A. D. Sanders.

[2] Supplied by Mr. D. Laxminarayan. They are figures of railings. The total output from Laxminarayan's deposits was given to me as approximately 23,000 tons, but as most of this was no despatched, it will probably be included in the output figures for 1907 and hence I have given the figures of railing.

TABLE 31.

Detailed production of the Bhandára district in long tons.

	1901	1902	1903	1904	1905	1906	Total for each deposit.	Total for each syndicate, etc.
Central Provinces Prospecting Syndicate [1].								
2. Sitapathur . . .	..	..	..	..	..	1,791	1,791	
10. Kurmura (Ponwárdongri) .	..	248	..	..	1,456	4,842	6,546	
11. Chikhla I . . .	499	5,112	4,998	8,559	14,791	27,678	61,637	
YEARLY TOTALS .	499	5,360	4,998	8,559	16,247	34,311	69,974	69,974
Central India Mining Co. [2]								
1. Kosumba . . .	..	..	..	..	8,105	17,682	25,787	
3. Sukli	..	..	..	..	3,519	16,529	20,048	
4. Hatora	..	..	..	..	113	2,509	2,622	
5. Miragpur . . .	..	..	..	..	6,554	14,386	20,940	
YEARLY TOTALS .	..	..	..	..	18,291	51,106	69,397	69,397
Jessop & Co. [3]								
14. Pachára . . .	..	..	..	..	700	600	1,300	
YEARLY TOTALS .	..	..	..	..	700	600	1,300	1,300
D. Laxminarayan [4].								
Paraswára Ghát . .	..	..	..	..	..	16	16	
13. Asalpáni II (Karli) . .	..	..	..	..	..	11,873	11,873	
YEARLY TOTALS .	..	..	..	..	..	11,889	11,889	11,889
GRAND YEARLY TOTALS .	499	5,360	4,998	8,559	35,238	97,906	..	152,560

Grand total for the whole district, 1901 — 1906 = 152,560 tons.

[1] Supplied by Mr. A. D. Sanders.
[2] Supplied by Mr. H. D. Coggan.
[3] Supplied by Mr. E. S. T. Davies ; evidently approximate.
[4] Supplied by D. Laxminarayan; they are amounts of ore railed.

TABLE 32.

Detailed production of the Chhindwára district in long tons.

	1906	Total for each deposit.	Total for each producer.
Indian Manganese Co.[1]			
1. Kachi Dhána	3,713	3,713	
3. Gaimukh	205	205	
4. Sitapár	1,699	1,699	
10. Gowári Warhona . . .	1,269	1,269	
TOTAL .	6,886	6,886	6,886
Mathura Prasad.			
7. Devi	600	600	
TOTAL .	600	600	600
GRAND TOTAL .	7,486	7,486	7,486

Grand total for the whole district, 1903 = 7 486 tons.

[1] Supplied by Mr. C. W. Walsh.

TABLE 33.

Detailed production of the Nágpur district in long tons.

	1900.	1901.	1902.	1903.	1904.	1905.	1906.	Total for each deposit.	Total for each syndicate, etc.
Central Provinces Prospecting Syndicate. [1]									
2. Gumgáon .	..	3,117	1,731	1,981	220	2,409	3,222	12,680	
3. Rámdongri	..	1,355	..	997	..	3,031	258	5,641	
7. Kándri .	20,040	26,913	12,507	19,546	15,984	12,897	23,717	132,504	
8. Mansar .	22,913	27,031	15,924	13,523	13,293	16,497	18,731	127,912	
14. Sátak .	..	..	..	..	..	115	3,581	3,696	
15. Beldongri .	..	3,114	4,094	5,347	1,585	1,344	3,553	19,037	
18. Lohdongri	3,404	15,395	19,140	7,207	1,331	20,922	39,970	107,369	
YEARLY TOTALS	47,257	76,925	53,396	48,601	32,413	57,215	93,032	408,839	408,839
Central India Mining Co. [2]								(50,437)	
9. Mansar Extension.					835	637	..	1,472	
10. Parsoda .					160	494	..	654	
14. Sátak .					377	1,248	3,193	4,818	
19. Kácharwáhi	..	..	15,423	35,014	3,063	8,379	5,340	16,782	
20. Waregáon .					2,973	..	2,538	5,511	
22. Mándri .					11,745	12,769	4,471	28,985	
22A. Panchála.					..	..	1,791	1,791	
23. Máncgáon .					5,576	8,227	15,525	29,328	
YEARLY TOTALS	..	..	15,423	35,014	24,729	31,754	32,858	139,778	139,778
Indian Manganese Co. [3]									
1. Kodegáon .	..	..	..	11,436	9,000	11,094	9,657	41,187	
YEARLY TOTALS .	..	..	..	11,436	9,000	11,094	9,657	41,187	41,187

[1] Supplied by Mr. A. D. Sanders. The reason for the difference between these figures and those that have been incorporated in the Mineral Production is that the figures given here represent actual amounts raised, whilst those given in the Mineral Production are at least partly figures of despatch and not of output (See page 432.)

[2] Supplied by Mr. H. D. Coggan. For the first two years the output figures of the various deposits were not kept separately. Of the 50,437 tons of manganese-ore quarried in these two years, 1902 and 1903, probably 25,000 to 30,000 tons came from Waregáon.

[3] Supplied by Mr. C. W. Walsh for 1905 and 1906. Figures for 1903 and 1904 are of doubtful accuracy. No exact figures seem to be available; those given are based on information from various sources.

TABLE 33—*contd.*

Detailed production of the Nágpur district in long tons.

	1900.	1901.	1902.	1903.	1904.	1905.	1906.	Total for each deposit.	Total for each syndicate, etc.
Jessop and Co. [1]									
24. Guguldoho	..	..	..	..	..	..	1,121	..	
25. Bhandárbori	..	..	..	..	..	..	3,600	..	
YEARLY TOTALS .	..	..	..	..	..	..	4,721	4,721	4,721
Madhu Lall Doogar Mining Syndicate. [2]									
29, 30, and 31. Mándvi Bir, Junawáni, and Junapáni . .	..	..	..	..	..	..	4,258	..	
YEARLY TOTALS .	..	..	..	..	..	..	4,258	4,258	4,258
D. Laxminarayan. [3]									
7. Kándri .	..	..	..	..	..	..	849	..	
12. Pársioni .	..	..	..	..	..	..	742	..	
YEARLY TOTALS .	..	..	..	..	..	..	1,591	1,591	1,591
GRAND YEARLY TOTALS . .	47,257	76,925	68,819	95,051	66,142	100,063	146,117	..	600,374

Grand total for the whole district, 1900—1906=600,374 tons.

[1] Supplied by Mr. E. S. T. Davies. As I saw a large quantity of ore stacked on the top of Guguldoho Hill in 1904 and a smaller amount at Bhandárbori, it is probable that the figures given here represent the amounts of ore despatched and not the amount quarried. I am not certain that the Guguldoho and Bhandárbori of Jessop & Co. correspond exactly with the deposits that I have described under these names.

[2] Supplied by Mr. Madhu Lall Doogar. Probably figures of ore despatched, and not of ore quarried and including ore raised in 1903-04.

[3] Supplied by Mr. D. Laxminarayan. They are amounts despatched.

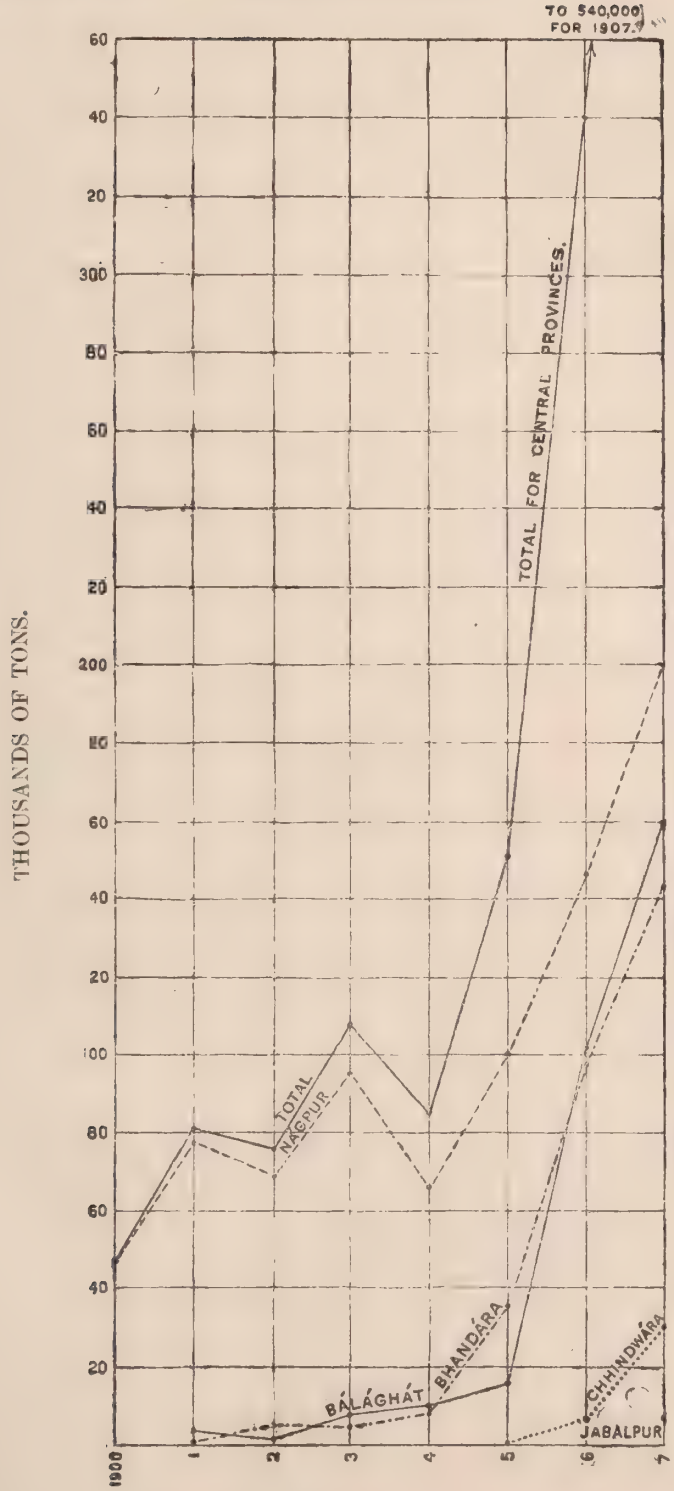

Fig. 25.—Diagram showing the annual manganese-ore production of the different districts of the Central Provinces.

TABLE 34.

Detailed production of the remaining provinces, in long tons.

Province.	District or State.	Operator and Mine.	1903.	1904.	1905.	1906.	District totals.	Province totals.
Bengal	Singhbhum[1]	*Madhu Lall Doogar Mining Syndicate :—*						
		South of Chaibása	..	..	..	1,000	1,000	1,000
Bombay	Belgaum[2]	*C. P. Boyce :—*						
		Nersa	..	..	40	..	..	
		Talevádi	..	..	600	234	874	
	Panch Mahás[3]	*Shivrajpur Syndicate :—*						
		Sivarájpur	..	..	..	7,286	7,286	
	TOTALS FOR BOMBAY		..	..	640	7,520	..	8,160
Central India	Jhábua[4]	*Kiddle, Reeve & Co. :—*						
		Kájlidongri	6,800	11,564	30,251	50,074	98,689	98,689
Madras	Sandur[5]	*Jambon & Cie. :—*						
		Rámandrug	..	..	1,200	447	..	
		Kannivihalli	..	..	..	2,762	..	
		TOTALS FOR SANDUR	..	..	1,200	3,209	4,409	4,409
Mysore	Chitaldrug[7]	*Peninsular Minerals Co. of Mysore*	..	..	..	712	712	
	Shimoga[6]	*Mysore Manganese Co.*						
		Short's Block	..	..	..	4,000	..	
		Kumsi (Holmes' Block)	..	..	..	36,773	..	
		TOTAL FOR SHIMOGA	..	..	..	40,773	40,773	
	Tumkur[7]	*Peninsular Minerals Co. of Mysore*	..	..	..	4,827	4,827	
	TOTAL FOR MYSORE		..	..	..	46,312	..	46,312

[1] A rough estimate by Mr. I. Shrager. No ore despatched.
[2] Supplied by Dr. C. P. Boyce.
[3] Supplied by Mr. F. A. East.
[4] Shipment figures, not production.
[5] Supplied by Mr. C. Aubert and A. Ghose.
[6] Supplied by Dr. Smeeth, State Geologist for Mysore.
[7] Supplied by Mr. R. T. Coggan.

TABLE 35.

Annual production of manganese-ore in India, by districts, states, and provinces, in long tons.

Year.	BENGAL.	BOMBAY.			CENTRAL INDIA.	CENTRAL PROVINCES.					MADRAS.			MYSORE.				Total for each year for the whole of India.
	Singhbhum.	Belgaum.	Panch Mahals.	Total.	Jhábua.	Bálághát.	Bhandára	Chhindwára.	Nágpur.	Total.	Sándur.	Vizagapatam.	Total.	Chitaldrug	Shimoga.	Tumkur.	Total.	
1892 .	..	..	..	..	..	..	..	..	..	..	..	674	674	..	..	..	..	674
1893 .	..	..	..	..	..	..	..	..	..	..	..	3,130	3,130	..	..	..	..	3,130
1894 .	..	..	..	..	..	..	..	..	..	..	..	11,410	11,410	..	..	..	..	11,410
1895 .	..	..	..	..	..	..	..	..	..	..	..	15,816	15,816	..	..	..	..	15,816
1896 .	..	..	..	..	..	..	..	..	..	..	..	56,869	56,869	..	..	..	..	56,869
1897 .	..	..	..	..	..	..	..	..	..	..	..	74,467	74,467	..	..	..	..	74,467
1898 .	..	..	..	..	..	..	..	..	..	..	..	62,980	62,980	..	..	..	..	62,980
1899 .	..	..	..	..	..	..	..	..	..	..	..	84,652	84,652	..	..	..	..	84,652
1900 .	..	..	..	..	..	..	..	..	47,257	47,257	..	92,008	92,008	..	..	..	..	139,265
1901 .	..	..	..	..	..	3,839	499	..	76,925	81,263	..	76,473	76,473	..	..	..	..	157,736
1902 .	..	..	..	..	..	1,975	5,360	..	68,819	76,154	..	68,171	68,171	..	..	..	..	144,325
1903 .	..	..	..	..	6,800	7,898	4,998	..	95,051	107,947	..	63,074	63,074	..	..	..	..	177,821
1904 .	..	..	..	..	11,564	10,323	8,559	..	66,142	85 024	..	53,602	53,602	..	..	..	..	150,150
1905 .	..	640	..	640	30,251	16,246	35,238	*Nil.*	100,063	151,547	1,200	63,789	64,989	..	..	..	..	247,427
1906 .	1,000	234	7,286	7,520	50,073	102,260	96,017	7,486	146,117	351,880	3,209	111,501	114,710	712	40,773	4,827	46,312	571,495
TOTALS.	1,000	874	7,286	8,160	98,688	142,541	150,671	7,486	600,374	901,072	4,409	838,616	843,025	712	40,773	4,827	46,312	1,898,257
Province totals.	1,000			8,160	98,688					901,072			843,025				46,312	1,898,257

Grand total of ore raised in India from 1902 to 1906=1,898,257 tons.

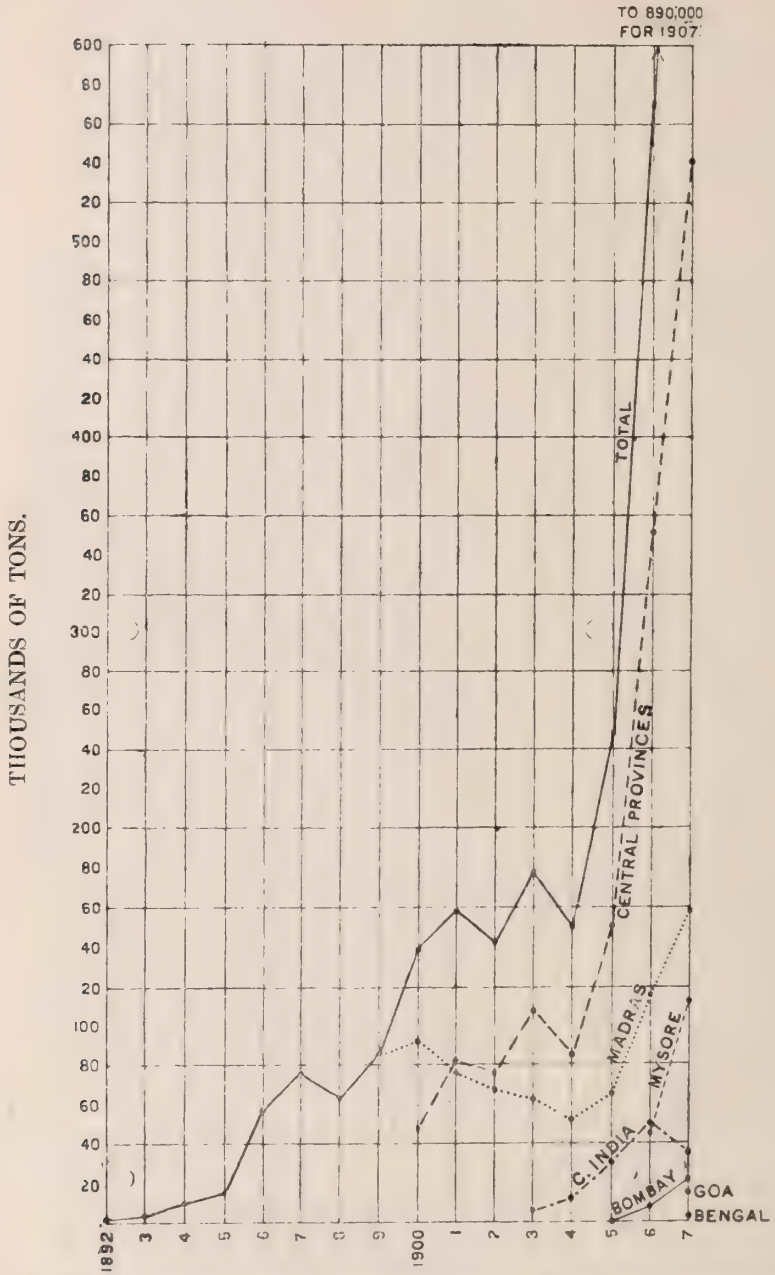

Fig. 26.—Diagram showing annual manganese-ore production of the different provinces of India since 1892.

In the foregoing tables I have given the figures of output of the different manganese-ore deposits of India as supplied to me personally by the various mine managers and agents. Below I give the figures for production as given in the Statistics for Mineral Production published annually by the Government of India, formerly in the publications of the Statistics Department, and now in the Records of the Geological Survey of India. I give these figures because they are the ones that have been quoted in all previous publications either in India or abroad.

TABLE 36.

Production of manganese-ore in long tons as given in the 'Mineral Production of India'.

Year.	Bombay.	Central India.	Central Provinces.	Madras.	Total.
1893	..	..	..	3,130	3,130
1894	..	..	..	11,410	11,410
1895	..	..	..	15,816	15,816
1896	..	..	..	56,869	56,869
1897	..	..	..	73,680	73,860
1898	..	..	..	60,449	60,449
1899	..	..	..	87,126	87,126
1900	..	..	35,356	92,458	127,814
1901	..	..	44,428	76,463	120,891
1902	..	..	89,609	68,171	157,780
1903	..	6,800	101,554	63,452	171,806
1904	..	11,564	85,034	53,699	150,297
1905	..	30,251	159,950	63,695	253,896
1906	7,517	50,074	320,759	117,380	495,730

A perusal of the foregoing tables of figures reveals several interesting facts. The first is that the total production of the Indian manganese-ore deposits since the commencement of the industry in 1892 has increased from 674 tons in 1892 to nearly 600,000 tons in 1906. The totals are

divided between the various districts, states and provinces in the following way:—

TABLE 37.

Total production of each district, state, and province, in long tons.

Province.	District or State.	Total output of District or State.	Total output of Province.
Bengal	Singhbhum	1,000	
		Total	1,000
Bombay	Belgaum	874	
	Panch Mahâls	7,286	
		Total	8,160
Central India . . .	Jhábua	98,688	
		Total	98,688
Central Provinces . .	Bálághát	142,541	
	Bhandára	150,671	
	Chhindwára	7,486	
	Nágpur	600,374	
		Total	901,072
Madras	Vizagapatam	828,616	
	Sandur	4,409	
		Total	843,025
Mysore	Chitaldrug	712	
	Shimoga	40,773	
	Tumkur	4,827	
		Total	46,312

Grand total for the whole of India=1,898,257 tons.

From this table it is seen that the total production of India from 1892 to end of 1906 is 1,898,257 tons, or roughly 1,900,000 tons, or an average of about 126,500 tons a year.

From the foregoing tables it is also seen that there are several deposits from which over 100,000 tons have been extracted since their opening up. For comparison they are collected in the following table (together with Kájlidongri, which has yielded nearly 100,000 tons) :—

Deposits that have yielded over 100,000 tons.

TABLE 38.

List of Indian deposits from which over 100,000 tons of manganese-ore have been extracted up to end of 1906.

Deposit.	District or State.	Period of work.	Total output.	Average annual output.	Maximum output in one year.
Garbhám . .	Vizagapatam	1896–1906	496,878	45,171	56,195 (1900)
Kodur Mines[1] . .	Do.	1892–1906	258,929	17,262	29,312 (1889)
Kándri . .	Nágpur	1900–1906	132,504	18,929	26,913 (1901)
Mansar . .	Do.	Do.	127,912	18,273	27,031 (1901)
Bálághát . .	Bálághát	1901–1906	118,419	19,736	78,499 (1906)
Lohdongri . .	Nágpur	1900–1906	107,369	15,388	39,970 (1906)
Kájlidongri . .	Jhábua	1903–1906	98,688	24,672	50,073 (1906)

Total average annual output of these 7 deposits=159,431 tons.

Total output of these 7 deposits=1,340,699 tons.

Of the remaining deposits there are a few others to be compared with these in point of size that will probably have produced 100,000 tons of ore in the next 5 years. These are Kumsi in Shimoga, and possibly some of the Sandur deposits. It is interesting to note that these 7 deposits have yielded between them 1,340,699 tons of ore, or 71 per cent. of the total output of India since the commencement of the industry.

It will be interesting at this point to compare the figures and curves of prices of manganese-ore given on pages 415 to 419, with the figures and curves showing the output of manganese-ore in India. It will be seen that the first exports from the Vizagapatam deposits took place when the

Comparison of prices with figures of production.

[1] The Kodur Mines include 5 separate workings, of which Kodur is the largest. They are, however, all on one band of manganiferous rock, and can therefore be included here. In any case the output of Kodur alone must be considerably over 100,000 tons.

price was 14 to 15 pence, and from the Central Provinces after the price had descended below one shilling and had again risen to a maximum, namely 13 to 15 pence, in 1900. From this time there was an almost continuous decline in prices till a minimum of $8\frac{3}{4}$ to $9\frac{1}{4}$ was reached in 1905. This was accompanied by a decline in the output of the Vizagapatam mines, the figure for 1904 being only 53,602. There was also a small decline in the output of the Central Provinces mines, the total for this year being only 85,000 tons. Towards the end of 1905 the price began to rise rapidly and almost continuously, 15 to 16 pence being reached in 1906. The result has been not only an unexampled increase in the output of the deposits already opened up, but also active prospecting all over India, with the resultant discovery of many new deposits. A start was made on the Sandur deposits during 1905 and on the Sivarájpur deposit in the Panch Maháls and the Mysore deposits during 1906. Another attempt was also made to work the Singhbhum deposits, but no ore was despatched to the rail. As a result of this extraordinary expansion in the Indian manganese industry, India, in 1905, took the second place amongst the world's manganese-ore producers with an output of 246,827 tons. In 1906 the total production of India was 571,495 tons. I do not know what the Russian production was during this year; but the export figures as estimated from arrivals at destination ports were 468,342; allowing a little over 60,000 tons for internal consumption, we get 530,000 tons as the exports plus consumption for 1906.

On account of the internal troubles in Russia during this year it is not improbable that the production was less than the above figure, the exports being partly made up of accumulated stocks. Hence there seems to be little doubt that India holds first place as regards manganese-ore output for 1906. The same remark applies to 1907, for which year the Indian output may be placed provisionally at about 850,000 tons. Up till 1905 India was run very closely for second place by Brazil. But the latter country now seems to have dropped behind, for its exports figure, which was 224,377 tons in 1905, dropped to 121,331 tons in 1906, in spite of the elevated prices. The cause for the increased prices for manganese-ore during 1906 and 1907 and the enormous increase in the demand for Indian ore was probably in part the disturbed state of Russia, which until 1905 and 1906 used to supply about one half the world's demand; and in part a period of great prosperity in the steel industry.

The figure of 15 to 16 pence for first grade ore reached at the end of 1906 was maintained for the first four months of 1907. Prices have

since been on the down grade, and, since September, 1907, have fallen rapidly, to 10 pence in February, 1908, and then to 9 pence in August, 1908: and this decline will no doubt seriously affect the Indian output for 1908.

Comparison of Indian and foreign manganese-ore production.

The growth of the Indian manganese-ore industry and its importance as compared with that of other countries can be best understood from the following table, in which are given the output figures of all the manganese-ore producing countries for the last ten years. These figures are taken mainly from the 'Mineral Industry', and are expressed in metric tons. Where it has been necessary to convert long tons into metric tons, it has been done on the basis of 1 long ton = 2,240 lbs., and 1 metric ton (1,000 kilogrammes) = 2,204·62 lbs. In figure 27 the production from 1890 to 1906 of the four countries, India, Russia, Brazil, and Spain, the only ones that have ever produced 100,000 tons of manganese-ore in one year, is shown graphically.

In table 40 similar figures are given for the output of manganiferous iron-ores. According to the practice in the United States of regarding all ores containing less than 44 per cent. manganese as manganiferous iron-ores rather than as manganese-ores, a certain proportion of the Indian production (say 50,000 tons in 1906) should be classed under this heading.

In table 41 I have given the totals for the annual output of the whole world of manganese-ores and manganiferous iron-ores. It will be seen that the production of manganese-ores has increased from 368,671 tons in 1890 to 1,445,496 tons in 1906, and of manganiferous iron-ores from 245,572 in 1890 to 922,751 in 1905.

TABLE 39.

World's production of manganese-ores from 1890 to 1906.

(In metric tons, unless otherwise indicated.)

Year.	Austria.	Borneo.	Bosnia and Herzegovina.	Brazil*.	Canada. (*k*)	Chile*.	Colombia.	Cuba* (*c*).	France.	Greece.	Hungary.	India (*e*).
1890	8,007	..	5,500	..	1,205	50,997	..	22,160	15,984	13,547	1,445	..
1891	5,279	..	2,847	..	231	35,610	..	22,340	15,343	13,453	2,233	..
1892	4,558	..	7,944	..	134	51,685	..	19,052	32,406	11,716	786	685
1893	5,411	..	7,403	*Nil*	193	36,741	..	10,811	38,080	5,250	1,238	3,180
1894	5,055	..	6,588	1,390	67	47,994	..		32,751	9,319	3,953	11,593
1895	4,352	..	8,145	5,490	113	24,075	6,025	1,416	30,871	7,250	3,525	16,032
1896	3,950	..	6,821	14,120	112	26,151	10,668	*Nil*	31,318	15,500	2,101	57,781
1897	6,012	..	5,344	16,054	14	23,529	8,382	*Nil*	37,212	11,868	4,030	75,662
1898	6,132	..	5,320	26,417	45	20,851	11,176	965	31,935	14,097	8,087	63,990
1899	5,411	..	5,270	65,000	1,434	40,931	10,160	13,906	39,897	17,600	5,073	86,011
1900	8,804	..	7,939	108,244	27	25,715	8,748	22,963	28,992	8,050	5,746	141,498
1901	7,796	..	6,346	100,414	399	18,180	95	25,587	22,301	14,166	4,591	160,267
1902	5,646	..	5,760	157,295	156	12,990	*Nil*	40,264	12,536	14,960	7,237	146,641
1903	6,479	..	4,538	161,926	122	17,110	..	19,097	11,583	9,340	5,311	180,675
1904	10,189	..	1,114	208,260	112	2,324(*p*)	..	15,765	11,251	8,549	11,527	152,601
1905	13,788	..	4,129	224,377	20	1,324(*p*)	..	7,018	6,751	8,171(*e*)	9,943	250,788
1906	13,402(*a*)	2,845(*j*)	7,651(*f*)	121,331	84	(*a*)	..	18,988	11,189	[illegible] (*f*)	10,894(*f*)	579,231
Totals	**119,971**	**2,845**	**104,659**	**1,210,318**	**4,438**	**436,507**	**55,254**	**240,332**	**410,406**	**192,876**	**87,720**	**1,926,935**

(*a*) Not reported; (*c*) Taken from table 35 and converted into metric tons; (*e*) Taken from the Mineral Resources of the United States and, where necessary, converted to metric tons. (*f*) Taken from the *Mining Journal* and, where necessary, converted to metric tons.
(*j*) Figures of arrivals in consuming countries, kindly supplied by Messrs. Macqueen Brothers; converted from long tons.
(*k*) Converted from official statistics. (*o*) Taken from *Annales des Mines*. (*p*) British Home Office Reports. * Exports.

TABLE 39—*continued.*

Year.	Italy.	Japan.	Java. (*e*)	New Zealand.	Portugal.	Queensland.	Russia.	South Australia.*	Spain.	Sweden.	Turkey.	United Kingdom. (*h*)	United States. (*e*)
1890	2,147	2,596	..	490 *	(*e*)*	5(*e*)	182,468	2,808	9,872	10,698	..	12,646	26,096
1891	2,429	3,229	..	1,175	3,105(*b*)	10(*e*)	113,081	861	6,993	9,097	..	9,632	23,792
1892	1,243	5,027	..	529	3,399	(*a*)	203,237	715	16,910	7,832	..	6,175	13,831
1893	810	14,169	..	324	4,080	(*a*)	268,621	2,467	1,460	7,061	2,900* (*b*)	1,357	7,842
1894	760	13,368	..	544	5,246	142	243,469	177	340	3,359	2,225* (*b*)	1,838	6,409
1895	1,569	17,142	..	213	1,240	361	203,081	49	10,162	3,117	8,400* (*b*)	1,293	9,700
1896	1,890	17,967	3,000*(*b*)	66	1,494	305	208,025	(*a*)	38,265	2,056	33,500* (*b*)	1,097	10,250
1897	1,634	15,448	5,200(*b*)	183	1,652	403	370,190	(*a*)	100,566	2,749	49,000* (*b*)	609	11,286
1898	3,002	11,497	4,800(*b*)	220	907	68	329,276	5	102,228	2,358	.. (*e*)	235	16,213
1899	4,356	11,336	1,388(*b*)	137	2,949	747	659,301	102	104,974	2,622	48,689* (*b*) (*e*)	422	10,094
1900	6,014	15,831	..	166	1,971	77	802,234	(*a*)	112,897	2,651	38,100* (*b*)	1,384	11,960
1901	2,181	16,270	..	211	904	221	522,395	134	60,325	2,271	46,000 (*e*)	1,673	12,187
1902	2,477	10,844	..	..	(*a*)	4,674	536,518	18	46,069	2,850	50,000 (*e*)	1,299	7,597
1903	1,930	5,616	..	71	30	1,341	415,285(*l*)	10	26,194	2,244	49,100 (*e*)	831	2,870
1904	2,836	4,324(*p*)	726(*j*)	199	1,851	843	421,039(*l*)	(*a*)	18,732	2,297	49,100*(*e*)	8,896	3,196
1905	5,384	11,162(*e*)	1,600	56	(*a*)	1,541	433,646(*l*)	(*a*)	26,020	1,992	28,600*(*e*)	14,582	4,118
1906	3,060(*f*)	4,370*	890(*j*)	16	22	1,131	530,000(*m*)	(*a*)	79,994(*j*)	300(*j*)	19,900* (*f*)	23,126	7,032
Totals	**43,722**	**180,196**	**17,604**	**4,600**	**28,850**	**11,869**	**6,441,866**	**7,346**	**762,001**	**65,536**	**425,514**	**87,096**	**184,473**

(*a*) Not reported ; (*b*) Not known what sort of ton ; (*e*) Taken from the Mineral Resources of the United States and where necessary converted to metric tons. (*f*) Taken from the *Mining Journal* and where necessary converted to metric tons.

(*h*) Low-grade ferruginous ores.

(*j*) Figures of arrivals in consuming countries kindly supplied by Messrs. Macqueen Brothers ; converted from long tons.

(*l*) Taken from Mineral Resources of United States, and converted at 61·05 poods=1 metric ton.

(*m*) The figure supplied by Messrs. Macqueen Brothers is 468,342, and does not account for internal consumption, assumed to be 60,000 to 70,000 tons annually. (*p*) British Home Office Reports. * Exports.

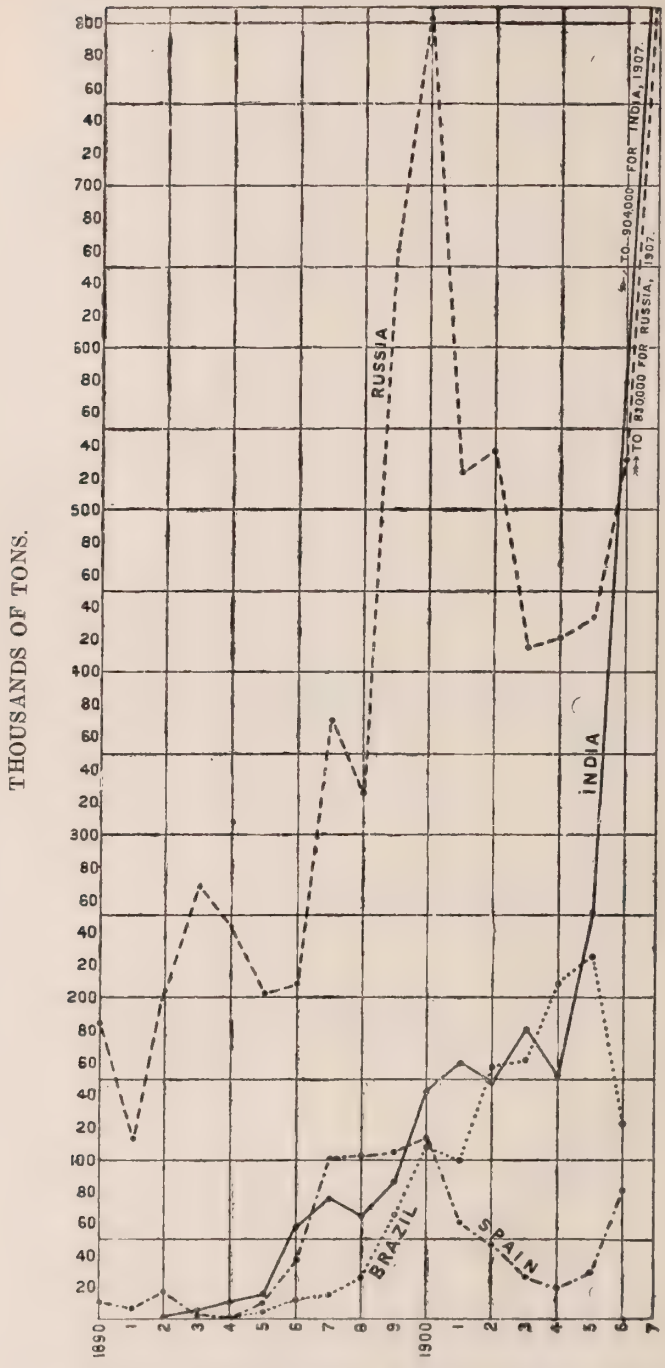

Fig. 27.—Diagram showing manganese-ore production since 1890 of the four leading countries.

TABLE 40.

World's production of manganiferous iron-ores from 1890 to 1906.

(In metric tons, unless otherwise stated.)

Year.	Belgium.	Germany (*m*).	Greece.	Italy.	United States (*e*)
1890	14,255(*e*)	41,841	126,620	..	62,856
1891	18,498	40,355	108,733	(*a*)	134,637
1892	16,755	32,861	157,756	4,622	155,834
1893	16,820	40,798	121,352	8,805	119,403
1894	22,048	43,702	159,080	5,810	208,785
1895	22,478	41,327	152,123	5,860	127,746
1896	23,265	45,062	166,850	10,000	344,147
1897	28,372	46,427	182,850	21,262	205,550
1898	16,440	43,354	213,938	11,150	292,428
1899	12,120	61,329	294,320	29,874	774,071
1900	10,820	59,204	243,920	26,800	383,636
1901	8,510	56,691	196,152	24,290	583,708
1902	14,440	49,812	170,040	23,113	915,676
1903	6,100	47,994	152,740	4,735	593,873
1904	485	52,886	239,635	*Nil*	389,393
1905	..	51,463	89,687	*Nil*	781,601
1906	..	52,485	96,382	..	1,000,000(*n*)
Totals excluding 1906.	231,405	755,106	2,775,796	176,321	7,073,344

(*a*) Not reported. (*e*) Taken from the Mineral Resources of the United States.
(*m*) Includes a certain amount of true manganese-ore
(*n*) A very rough estimate.

TABLE 41.

World's total production of manganese-ores and manganiferous iron-ores from 1890 to 1906.

(Metric tons.)

	Manganese-ores.	Manganiferous iron-ores.
1890	368,671	245,572
1	276,722	302,223
2	387,834	367,828
3	419,398	307,178
4	396,587	439,425
5	363,621	349,534
6	486,437	589,324
7	747,027	484,461
8	659,824	577,310
9	1,137,810	1,171,714
1900	1,360,011	724,380
1	1,025,217	869,351
2	1,065,831	1,173,081
3	921,403	805,442
4	935,734	682,399
5	1,055,010	922,751
6	1,445,496	1,148,867
Total production, 1890–1906.	13,052,633	11,160,840
Average annual production, 1890–1906.	767,802	656,520
Average annual production, 1901–1906.	1,074,782	933,648

Exports of Indian manganese-ore.

For comparison with the annual figures of production of manganese-ore in India, given in table 35, I give below the figures for the export of manganese through the four ports of Vizagapatam, Bombay, Calcutta, and Mormugáo [1]:—

TABLE 42.

Exports of Indian manganese-ore from 1892 to 31st March 1907.

Long tons.

Year.	Vizagapatam.	Bombay.	Calcutta.	Mormugáo.	Yearly totals.
1892–93	1,000				1,000
1893–94	1,650				1,650
1894–95	6,416				6,416
1895–96	22,758				22,758
1896–97	47,330				47,330
1897–98	78,829				78,829
1898–99	62,875				62,875
1899–1900	95,225				95,225
1900–01	100,770	29,900			130,670
1901–02	78,820	54,350			133,170
1902–03	60,680	94,227	367		155,274
1903–04	61,850	110,796	8,543		181,189
1904–05	52,925	121,015	7,005		180,945
1905–06	64,275	236,059	16,360	9,550	326,244
1906–07	106,535	350,543	35,915	61,199	554,192
Total for each port.	841,938	996,890	68,190	70,749	1,977,767

Total exports of manganese-ore from India, 1892–1907 = 1,977,767 long tons.

[1] Annual Statements of Trade and Navigation of British India, Volume I. of each year, except the figures of Mormugáo, the figures for which were kindly supplied by the British Consul at Goa.

From the foregoing table it will be seen that the total exports from the beginning of the manganese industry in India up to the end of the year ending 31st March 1907, namely 1,977,767 tons, is more than the total production from the Indian deposits from the beginning of the industry to the end of the calendar year 1906, namely 1,898,257 tons, by 79,510 tons. This excess can be explained as due to some of the ore exported during the first quarter of 1907 having been mined in that quarter, so that it has not been included in the total production up to the end of 1906; and also as partly due to some ore raised in Portuguese territory having been exported, but not included in the Indian output figures.

Distribution of the Indian manganese-ore exports.

I can appropriately close this section with the following table showing the distribution of the exported ores amongst the various steel-making countries.

TABLE 43.

Distribution of exported Indian manganese-ore for the years 1895-1896 to 1906-1907.

Long tons.

Year.	United Kingdom.	Belgium.	France.	Germany	Holland.	Egypt.	United States.	Other countries.	Total recorded export for the year.
1895–96	19,358	..	..	..	..	..	3,400	..	22,758
1896–97	42,630	..	..	..	..	..	4,700	..	47,330
1897–98	54,279	..	..	..	..	..	24,550	..	78,829
1898–99	51,931	..	..	..	..	..	10,944	..	62,875
1899–00	63,175	5,350	..	..	8,350	..	18,350	..	95,225
1900–01	86,269	13,300	5,850	..	16,500	3,400	5,350	..	130,669
1901–02	65,150	..	..	11,300	..	15,000	41,720	..	133,170
1902–03	95,540	1,000	..	10,734	5,050	..	42,950	Italy, 1 cwt. Japan, 1 cwt.	155,274
1903–04	110,506	19,288	2,050	9,985	3,500	..	35,860	..	181,189
1904–05	64,705	25,015	10,800	..	5,300	10,750	64,375	..	180,945
1905–06	127,856½	54,101	29,401	2 cwt.	2,400	3,900	96,835	10 cwts. Austria-Hungary 2,200	316,694
1906–07	219,607	98,581	33,485	—	2,000	—	139,320	Austria-Hungary 1 cwt.	492,993
Total sent to each country.	1,001,006½	216,635	81,586	32,019	43,100	33,050	488,354	2,200½	1,897,951

The three great steel-producing countries—England, United States and Germany—take a large proportion of our manganese-ore; the exports to Holland and Belgium shown in the above table were in part for transmission to Germany, whilst the consignments sent to Egypt were booked to Port Said to await delivery to ports further west.

Future Prospects of the Manganese Industry of India.

On this subject I cannot do better than quote what I said in my paper 'Manganese in India', pages 121 to 124:—

'It will be noticed that no estimate has been given in this paper of the quantities of manganese-ore available in the deposits. This is not, however, because there is any need for pessimism on the subject. It is true that in the Vizagapatam district it is becoming more difficult to quarry the ore owing to the increasing depth at which it has to be worked; but in the Central Provinces there are several deposits concerning which it is easy to form estimates indicating the presence of millions of tons of ore easy to win. Owing, however, to the insufficient work which has been carried out in the way of cross-cuts and bore-holes . . . . . , these estimates are more or less of guesses, but there can be no doubt whatever of their general correctness in pointing to the presence in the Central Provinces of vast quantities of easily quarried manganese-ore.

'Nevertheless, at the present rate of output, with the rejection of all but first-grade ore, there does not seem to be much doubt that within a comparatively small period of time, which one might guess at 30 to 50 years, the majority of the deposits at present known will have been worked out as far as the application of present methods of extraction are concerned. There will then still be left, both in the ground and on the dump-heaps, millions of tons of second- and third-grade ores and vast quantities of manganese-silicate rock consisting largely of spessartite and rhodonite, and often carrying as much as 30 to 40 per cent of manganese.

'This might be considered as rather an alarming prospect but for two counterbalancing considerations. One is that the deposits of manganese-oxide ores throughout the world are strictly limited in quantity, so that within a comparatively short time, which might be guessed as 100 years as a maximum, unless several fresh areas containing such deposits be discovered, all the easily won ores will have been removed from the earth. Long before that time, however, the price per unit of manganese will rise sufficiently to enable the lower grade ores of the world, if not smelted on the spot, to be transported profitably to the smelting centres. Long before that time also the increasing difficulty and cost of getting manganese-oxide ores will probably compel metallurgists to turn their attention to the silicate-ores.

'The second consideration is that long before that time, and let us hope in only a few years from the present, ferro-manganese smelting will probably have been introduced into India, thus rendering valuable the low-grade ores at present rejected, and so to a certain extent conserving the higher grade ores.

'We are thus able to picture that within a comparatively small number of years, the easily-won high-grade Indian oxide-ores will become quite limited in quantity, and that, with the rising prices due to a similar state of affairs in other parts of the world, the manganese-miners will then find it just as profitable to work the lower grade ores and sort over their dump-heaps as the tin-miners recently have in Cornwall to search their waste heaps for wolfram. Following this, will come the time when spessartite and rhodonite will be regarded as ores and just as eagerly sought as 50 per cent. oxide-ores now are.

'Keeping in view these three stages of manganese-mining—high-grade oxide ores, low-grade oxide-ores, and silicate-ores, being each in turn the substance sought—it can confidently be predicted that manganese- "quarrying," and later on perhaps, manganese- "mining," has in India a long and prosperous future with possibly, however, bad times at intervals.

'Nevertheless, it would not be out of place to draw attention to the desirability of stocking the low-grade and silicate-ores separately from the country-rock of quartzite, mica-schist, gneiss or lithomarge, with which they are often indiscriminately mixed when consigned to the waste-heaps.

'Another aspect of the question has already been noticed by Mr. Holland[1], namely the heavy loss which India, to all intents and purposes, suffers by exporting the raw ore. The average price that Indian manganese-ore fetches at its destination is about Rs. 30 per ton, and of this only about one-half goes to India, being divided between railways, carters, miners and land-owners. The remaining Rs. 15 goes mainly in freight charges. The mananese then comes back to India in the form of the steel it has helped to make, and India pays both the foreign manufacturer's profits and the cost of return carriage. A recent quotation in the *Engineering and Mining Journal*[2] gives the price per ton of 80 % ferro-manganese as $85 to $175, equivalent to about Rs. 265 to Rs. 546. It becomes obvious from this how desirable it is to manufacture ferro-manganese in India and thus keep in the country a proportion of the profits involved in its manufacture, even if the larger proportion of the ferro-manganese so made has still to be exported. The time must come, however, when the manufacture of iron and steel will be one of India's most important industries, and then, of course, India will consume a large proportion of its own ferro-manganese.'

The foregoing needs no modification except as regards the estimate, which is of course only a guess, as to how long it will take to work out the deposits at present known by open-cast methods. The guess given is 30 to 50 years. Considering the sudden leap in the Indian production for 1906 and the fact that the production for 1907 is even larger, it seems as if India has captured a considerable proportion of the world's market, so that even with the drop in prices recently experienced (end of 1907 and beginning of 1908) the production is not likely for the next few years to fall as low even as the figure for 1905. Bearing this in view I think that the 30 to 50 years is probably an over-estimate and that 20 to 30 would be a truer one for the number of years required for the working out of the ores at present in sight by open-cast methods, When I wrote the above, however, I had not seen the Sandur deposits. There can be no doubt as to existence of large quantities of manganese-ore—mostly second-grade, however—in the hills of this State. Making allowance for these I should be inclined to somewhat increase the estimate again, but not up to its former amount. With regard to the loss that India suffers by the export of manganese-ore in the raw condition see pages 541—3.

[1] *Rec. Geol. Surv. Ind.*, XXXII, p. 62, (1905)
[2] Jan. 27th, 1906, p. 212.

Appendix to Chapter XXII.

I give below the output statistics in long tons of the manganese industry in India for the year 1907; they were obtained too late to be incorporated in the tables given in this chapter.

TABLE 43A.

Province.	District or State.	Operator.	Deposit.	Production.	Totals for each operator.	Totals for each district.	Totals for each province.
Baluchistan.	Las Bela .	Pabb Syndicate.		15	15	15	15
Bengal .	Singhbhum	Madhu Lall Doogar Mining Syndicate.	5. Gitilpi .	1,304			
			7. Tutugutu .	2,229	3,533		
		Jambon & Cie.	6. Kalenda .	400	400	3,933	2,933[1]
Bombay .	Belgaum .	C. P. Boyce	Talevádi .	500	500	500	
	Panch Mahals.	Shivrájpur Syndicate.	Sivarájpur .	19,689	19,689		
		Bámankua Manganese Co.	Bámankua .	2,428	2,428	22,117	2,617
Central India.	Jhábua .	Kiddle Reeve & Co	Kájlidongri .	35,743[2]	35,743	35,743	35,743
Central Provinces.	Bálághát .	Central Provinces Prospecting Syndicate.	2. Thirori .	654			
			2. Ponia .	3,824			
			2. Jámrapáni	2,064			
			6. Ramrama	2,114			
			9. Bálághát .	92,182	1,00,838		
		D. Laxminarayan.	2. Thirori .	3,342			
			2. Jámrapáni	17,065			
			Gáraghát .	16,344			

[1] 1,000 tons, returned in the 1906 figures, deducted.
[2] Includes a small amount of ore won at Rambhápur.

Province.	District or State.	Operator.	Deposit.	Production.	Totals for each operator.	Totals for each district.	Totals for each province.
Central Provinces—*contd.*	Bálághát—*contd.*	D. Laxminarayan.	Sáori . .	812	37,563		
		Indian Manganese Co.	Langur .	1,934	1,934		
		Tata, Sons & Co.	Gudma . .	5,000	5,000		
		Carnegie Steel Co	Ukua . .	14,400	14,400	159,735	
	Bhandára	Central Provinces Prospecting Syndicate.	2. Sitapathúr .	392			
			10. Kurmura .	337			
			11. Chikhla I .	38,840	39,569		
		Central India Mining Co.	1. Kosumbah .	29,397			
			3. Sukli . .	30,615			
			4. Hatora .	2,121			
			5. Miragpur .	34,300			
			Bhumian .	2,794			
			Rámjitola .	1,564	100,791		
		D. Laxminarayan.	10. Kurmura .	499			
			13. Ásalpáni II	2,844	3,343	143,703	
	Chhindwára	Indian Manganese Co.	1. Kachi Dhána.	8,720			
			3. Gaimukh .	177			
			4. Sitapár	9,869			
			10. Gowári Warhona.	11,932	30 728	30,728	

Province.	District or State.	Operator.	Deposit.	Production.	Totals for each operator.	Totals for each district.	Totals for each province.
Central Provinces—*contd.*	Jabalpur.	Carnegie . Steel Co.	Mansakra .	7,100	7,100	7,100	
	Nágpur .	Central Provinces Prospecting Syndicate.	2. Gumgáon .	12,860			
			3. Rámdongri	5,928			
			7. Kándri .	30,307			
			8. Mansar .	24,974			
			14. Sátak .	7,789			
			15. Beldongri .	7,257			
			18. Lohdongri	40,418	1,29,553		
		Central India Mining Co.	14. Sátak .	1,598			
			17. Nandapuri .	537			
			19. Kácharwáhi	3,938			
			20. Waregáon .	528			
			22. Mándri .	7,056			
			22A. Panchála	536			
			23. Mánegáon .	11,270	25,463		
		Indian Manganese Co.	1. Kodegáon .	7,527	7,527		
		Jessop & Co.	24. Guguldoho .	3,002			
			25. Bhandárbori	3,837			
			Bhandachúr	967	7,806		
		Madhu Lall Doogar Mining Syndicate.	29-31. Mándvi Bir, Junawáni and Junapáni	16,200	16,200		
		D. Laxminarayan.	7. Kándri .	12,066			
			12. Pársioni .	495			
			21. Khandala	221	12,782	199,311	540,577

Province.	District or State.	Operator.	Deposit.	Production.	Totals for each operator.	Totals for each district.	Totals for each province.
Madras .	Sandur .	General Sandur Mining Co.	1. Rámandrug	15,455			
			2. Kannevihalli.	7,595			
				23,050	23,050	23,050	
	Vizagapatam.	Vizianagram Mining Co.	1 to 5. The Kodur Mines	17,435			
			7. Perapi .	9,160			
			10. Govindapuram.	787			
			11. Garbhám .	56,262			
			13. Gadasám .	459			
			14. Ávagudem	7,929			
			15. Aitemvalsa	1,216			
			18. Garuja .	2,876			
			19. Perumáli .	2,709			
			20. Rámabhadrapuram.	1,733			
			Bajuvalsa.	302			
			Batuva .	415			
			Boddam .	2,378			
			Chinna Palavalsa.	27			
			Chipurupalli.	834			
			Dannanapeta	842			
			Devarapilli	419			
			Gadabavalsa	416			
			Jada . .	890			
			Kottapetta	195			
			Lingalavalsa	2,108			
			Naiduvalsa	54			
			Nellimarla .	3,942			
			Vedullavalsa	903	114,291		

Province.	District or State.	Operator.	Deposit.	Production.	Totals for each operator.	Totals for each district.	Totals for each province.
Madras—*contd.*	Vizagapatam—*contd.*	Madras Manganese Company.	Baidapilli .	1,155			
			Batuva .	1,070			
			Boddam .	141			
			Buthara-yavalsa.	61			
			Challapuram	440			
			Chinna Ranyam.	2,329			
			Chipurupalli	503			
			Chokkara-palem.	264			
			4. Devâda .	1,351			
			Donnava-peta.	4			
			Gadabavalsa	962			
			13. Gadasâm .	54			
			11. Garbhâm .	3,961			
			1. Garividi .	2,055			
			18. Garuja .	16			
			16. Gotnandi .	165			
			10. Govinda-puram.	100			
			Gumadam .	586			
			Gunpam .	13			
			Kondapalem	40			
			Kothavalsa	376			
			Lakshmi-puram.	3,672			
			Lingalavalsa	48			
			Mukkunara Sannapeta.	5			

Province.	District or State.	Operator.	Deposit.	Production.	Totals for each operator.	Totals for each district.	Totals for each province.
Madras—*concld.*	Vizagapatam—*concld.*	Madras Manganese Company—*concld.*	Nimmalavalsa.	754			
			7. Perapi .	2			
			19. Perumáli .	640			
			Rávivalsa .	21			
			Regati .	4			
			Sarveswarapuram.	81			
			Sivandhoravalsa.	41			
			Vedudavalsa	145			
			Viswanadhapuram.	8			
			Viziarampuram.	2	21,878	136,169	159,219
Mysore .	Chitaldrug	Peninsular Minerals Co. of Mysore.			691		
		Haji Prosp Synd.			1,000		
		Various licensees.			1,434	3,125	
	Shimoga .	New Mysore Manganese Co.			76,894		
		Shimoga Manganese Co.			15,729		
		Tata, Sons & Co.			1,427		
		Jambon & Cie.			816		
		Various licensees.			1,725	96,591	
	Tumkur .	Peninsular Minerals Co. of Mysore.			13,091	13,091	112,807

The figures of production for 1907 given above are summarized below :—

Province.	District or State.	Output for each district or State.	Output for each province.
		Long tons.	Long tons.
Baluchistan	Las Bela	15	15
Bengal	Singhbhum	2,933	2,933
Bombay	Belgaum	500	
	Panch Mahâls	22,117	22,617
Central India	Jhâbua	35,743	35,743
Central Provinces	Bâlâghât	159,735	
	Bhandâra	143,703	
	Chhindwâra	30,728	
	Jabalpur	7,100	
	Nâgpur	199,311	540,577
Madras	Sandur	23,050	
	Vizagapatam	136,169	159,219
Mysore	Chitaldrug	3,125	
	Shimoga	96,591	
	Tumkur	13,091	112,807
GRAND TOTAL			873,911

The output recorded above shows that Kumsi—from which practically all the ore mined by the New Mysore Manganese Co. is extracted—and Chikhla I are to be added to the list, given in table 38, of deposits

from which over 100,000 tons have been extracted. The list now stands as follows:—

	Total output.	Average annual output.
Garbhám	553,140	46,095
Kodur	276,364	17,273
Bálághát	210,601	30,086
Kándri [1]	175,726	21,966
Mansar [2]	154,358	19,295
Lohdongri	147,787	18,473
Kájlidongri [3]	134,431	26,886
Kumsi [4]	113,667	56,833
Chikhla I	100,477	14,354

The total quantity of ore won from these deposits in 1907 was 425,121 tons; of this, 92,182 tons were obtained from the Bálághát deposit, this being the largest output of any deposit in India in any year.

The exports of manganese-ore for the year ending 31st March 1907 are shown below:—

Port.	Tons exported.
Vizagapatam	121,735
Bombay	384,115
Calcutta	42,569
Mormugáo	99,962 [5]
TOTAL	648,381

From this it will be seen that the production of manganese-ore in India in 1907 exceeded the exports by over 200,000 tons.

[1] Including the ore extracted by D. Laxminarayan.
[2] Including Mansar Extension.
[3] Including a little ore from Rambhápur.
[4] Probably includes a small amount of ore won from other deposits.
[5] Includes some 7,000 to 8,000 tons of ore mined in Goa.

CHAPTER XXIII.

ECONOMICS & MINING—*continued.*

Labour and Costs of Production.

Labour—Labour obtainable—Coolie wages—Contract and departmental labour—Absence of mining castes—Average daily number of workers—Benefits of the manganese industry.

Costs of mining and transport—Cost of mining—Of transport to railway—Of railway transport to port of shipment—Of handling at port of shipment—Of shipping to Europe and America—Insurance—Destination charges—Total costs of mining manganese-ore in India and putting it *c.i. f.* at foreign ports—Comparison of the cost of production of Indian, Russian, and Brazilian manganese-ores.

Royalty.

Labour.

Labour obtainable.

There is a considerable variation in the labour conditions obtaining in the different manganese-mining areas. The best miners I have seen are the Telugu-speaking natives of the Vizagapatam district, who seem to work considerably harder than the coolies employed in Central India and the Central Provinces. In Vizagapatam there seems to be no difficulty in obtaining a sufficiency of labour locally; but in Central India and the Central Provinces there is often considerable difficulty in obtaining a sufficient number of coolies to keep the mines in full work. In Jhábua in Central India, the natives are Bhils, who, apart from being rather lazy and casual in attendance, cannot be obtained in sufficient numbers; an additional supply of labour has therefore to be imported from other areas, such as Gujarátis from Ahmadábád. In the Central Provinces the labour locally obtainable consists of Hindus and the aboriginal Gonds. Here also the supply of labour is much less than the requirements, and consequently a further supply is imported from other parts of the Central Provinces, such as Raipur, and from other parts of India, such as Kachh in the Bombay Presidency. In Mysore the workers locally obtainable are Kanarese—mostly Lingáyats—, Waddas, and Lambádis; whilst Moplahs from Malabar, Waddas from Vellore in North Arcot, and coolies from the Western Ghâts, are imported. In the Sandur Hills it seems that no labour is locally obtainable and that it has all to be imported. The imported coolies consist of Kanarese and Lambádis from the districts of Bijapur, Dhárwár, and Bellary.

Coolie wages.

The wages paid to the ordinary coolies (men) and rezas (women) vary considerably from one area to another. The rates are shown in the following table as far as I have been able to ascertain them :—

TABLE 44.

Rates for coolie labour.

	Daily wages.		
	Men.	Women.	Children.
BENGAL :—	*Annas.*	*Annas.*	*Annas.*
Singhbhum	3	2	1½
CENTRAL INDIA :—			
Jhábua	2½	1½	1½
CENTRAL PROVINCES :—			
Bálághát	3–6	2–3	1–2
Nágpur	4–7	2½–3½	1–2
MADRAS :—			
Sandur	4–5	3	2–3
Vizagapatam	2½–3½	1¼–2	¾–1
MYSORE :—			
Shimoga	5–6	3–4	2–3
Tumkur	4–5	2–3	1–3

Contract and departmental labour.

It is only the ordinary unskilled coolies that are paid the above rates. On account of the frequency with which the coolies like to take holidays, owing to religious festivals or to the necessity of attending to crops, the mine managers find it preferable not to engage their coolies directly. The consequence is that most of the labour is supplied by contract, the contractor undertaking to extract and stack cleaned ore at a given rate per 1,000 cubic feet

measured as stacked, and to do dead-work at a given rate per 1,000 cubic feet of cavity made in the quarry in the case of soft 'deads', or per 1,000 cubic feet of rock measured in tubs or stacks in case of hard 'deads'. If the number of coolies employed by the contractor is small he pays them directly at about the rates given in the foregoing table; but if he is a large employer of labour he sublets his contract to a petty or gang contractor, to whom the contractor pays a smaller rate per 1,000 cubic feet of ore and dead-work. The petty contractor pays his gang—with whom he himself works as a common coolie, for he is no more—at rates approximating to those given in the table above.

Some classes of work it is of course either impossible or undesirable to let out to contractors. Amongst such work is that of carpenters, blacksmiths, and men in charge of the winding gear at mines where ropeways or gravity inclines are in use, men engaged in supervising tramming, and men engaged in drilling and blasting. Such men are said to be engaged departmentally and are paid by the mine manager either daily or monthly wages, according to the nature of the work on which they are engaged. For the commoner classes of departmental work the rates of pay are the same as given in table 44; but a considerable portion of the work being of a more skilled nature than the contract work, much higher wages than the above are often paid.

Absence of mining castes.

The difficulty of obtaining an abundant supply of good mining labour is partly due to the fact that the ancient mining industries of India have so long since decayed almost to the point of disappearance that there are very few people left whose caste work is mining. The consequence is that most of the coolies at present employed on the manganese mines have some other hereditary profession or trade, to which they like to revert at intervals. This particularly applies to the agriculturists, who have to absent themselves from the mines at certain times of the year so as to attend to the sowing and reaping of their crops. A further result of the coolies employed on the mines' not being hereditary miners is that they have no hereditary mining skill to bring to their work. Nevertheless, it often happens that whole families belonging to non-mining castes work on the manganese mines. Some of the children spend nearly the whole of their time on the mines practically from birth, and hence will grow up looking upon mining as their legitimate and proper occupation; from these, therefore, we may expect the evolution of a sort of mining caste during the course of the next generation or two.

Average daily number of workers.

The following table [1] shows the average daily number of workers—men, women, and children—employed in the manganese mines from 1895 to 1907 :—

TABLE 45.

Daily number of workers employed on the manganese-quarries from 1895 to 1907.

Year ending	Bombay.	Central Provinces.	Madras. (Vizagapatam).	Central India.	Mysore.	Total.
30th June 1895	...	..	600 to 1,100			600 to 1,100
30th June 1896	...	..	1,200			1,200
31st December 1897	..	..	2,750			2,750
31st December 1898	...	..	3,530			3,530
31st December 1899	..	..	4,780			4,780
31st December 1900	...	..	4,242			4,242
31st December 1901	..	1,460	2,770			4,230
31st December 1902	..	2,081	3,966			6,047
31st December 1903	..	4,003	2,939	(*a*)		6,942(*b*)
31st December 1904	125	2,010	1,980	(*a*)		4,115(*b*)
31st December 1905	48	2,566	2,508	876	(*a*)	5,998(*c*)
31st December 1906	271	5,154	5,848	1,334	(*a*)	12,607(*d*)
31st December 1907	1,099	9,23	8,419	(*a*)	(*a*)	18,751(*e*)

(*a*)—Figures not available.

(*b*)—Exclusive of Central India ; the figures for 1903 and 1904 may be estimated at about 230 and 390, respectively, at 30 tons per person per year.

(*c*)—Exclusive of Sandur and Mysore ; probably only a small number.

(*d*)—Exclusive of Singhbhum (Bengal), Sandur (Madras) and Mysore, probably about 1,500 more persons.

(*e*)—Exclusive of Singhbhum, Belgaum, Central India, Sandur, and Mysore.

[1] Compiled chiefly from the Annual Reports of the Chief Inspector of Mines in India.

The division of the labour in the districts of Bombay and the Central Provinces is shown in the following table :—

TABLE 46.

Daily number of workers employed in the manganese-quarries of Bombay and the Central Provinces, from 1900 to 1907.

Year.	BOMBAY.			CENTRAL PROVINCES.				
	Belgaum	Panch Mahâls.	Total.	Bâlâghât.	Bhandâra.	Chhindwâra.	Nâgpur.	Total.
1900 .	..	..	..	..	..	..	(a)	..
1901 .	..	..	..	(a)	(a)	..	1,460	1,460
1902 .	..	..	..	105	300	..	1,676	2,081
1903 .	..	..	..	385	75	..	3,543	4,003
1904 .	125	..	125	295	64	..	1,651	2,010
1905 .	48	(a)	48	362	300	..	1,904	2,566
1906 .	48	223	271	1,836	973	(a)	2,345	5,154
1907	..	1,099	1,099	2,663	2,230	416	3,924	9,233

(a)—Not returned, although work was progressing.

From the figures given in table 46 it will be seen that some of the totals for the Central Provinces given in table 45 are defective, and one of those for Bombay. It is also to be noticed that the figures are in many cases returned only when a deposit comes under the Mines Act. Taking into consideration the fact that statistics for 1906 are not available in the case of Bengal, Sandur, and Mysore, and are defective in the case of the Central Provinces, it is not improbable that the total average daily number of workers during this year was nearly 15,000. Taking the production totals for 1905 and 1906 as 245,627 and 513,488 respectively [including only Bombay, Central Provinces (except Chhindwâra), Central India, and Vizagapatam, the areas for which labour statistics are available] the average number of tons extracted during the year by each worker is 40·95 for 1905 and 40·73 for 1906.

Benefits of the manganese industry.

Allowing for cases that have escaped inclusion in the Annual Report of the Chief Inspector of Mines for 1906 it is probable that the average daily number of workers engaged in manganese mining in British India was about 12,000. This is equivalent to nearly 10 per cent. of the total number of persons engaged

in mining of all descriptions during 1906 in British India. It is, however, an insignificant portion of the total population of India.

Nevertheless, the influence of the manganese industry on the prosperity of the population of the areas where it exists is considerable. For in addition to coolies earning wages directly on the mines, a large number of the cultivators take up the work of carting manganese-ore, this often being a source of greater remuneration than actual working in the mines. Further, in areas, such as the Central Provinces, where there is a greater demand for labour on the mines than the available supply, the mines come into competition with the local Public Works Department and railway construction work, with the resultant forcing up the rates for coolie labour.

That the manganese-mining industry has a beneficial effect on the population of the mining areas is shown by the fact that, during the last famine in the Central Provinces, the natives round Rámtek, finding constant employment and wages in the neighbouring manganese mines, to a large extent escaped the worst effects of the famine. But it must not be overlooked that the industry must often be regarded with disfavour by those not actually connected with it, or benefiting as coolies in the general rise of wages for coolie labour. Thus they may have to put up with the proximity of large coolie camps; the roads are often very badly cut up by the manganese-ore carting traffic; whilst those who want to employ labour find it more expensive. It has been suggested by one of the mining community that a portion of the royalties received by Government from the manganese-ore industry might be applied in the manganese mining areas, either to reduce district cesses, or to improve communications, wells, schools, etc.

Costs of Mining and Transport.

The chief items in the cost of placing manganese-ore on the markets in Europe and America are the following:—

1. Cost of mining (labour, tools, plant, establishment).
2. Cost of transport to the railway.
3. Cost of transport to the port of shipment.
4. Cost of handling at the port of shipment.
5. Cost of shipping to Europe or America.
6. Destination charges.

Cost of mining.

The actual cost of winning the ore varies greatly from mine to mine, according to the character of the deposit, the methods employed in working it, and the cost of labour. The area concerning which I have the fullest information is the Central Provinces, to which the following remarks particularly apply, except where otherwise stated.

In the sort of quarry that can be described as a hole in the ground the actual cost per ton is not very much greater than that paid to the contractor. The rate paid to the contractor per 1,000 cubic feet of stacked and cleaned ore varies from Rs. 30 to Rs. 60 (and sometimes as high as Rs. 75), according to the ease with which the ore can be won (the lower rates apply to detrital ore and the higher to ore *in situ*), the distance the waste has to be taken to the dumps, and the situation of the deposit with relation to labour centres. I am told that it is found by actual experiment that the volume occupied by one ton of stacked and cleaned ore ranges from about 15 to 19 cubic feet, the commonest values being 16 and 17 cubic feet.

Taking 16½ cubic feet as an average value, the weight of 1,000 cubic feet of ore is about 60 tons, so that the cost per ton of ore works out at 8 annas to 1 rupee according as the rate paid to the contractor is Rs. 30 or Rs. 60 per 1,000 cubic feet. To allow for the fact that the proportion of ore to waste is very variable even in one mine, it is customary on some mines to make a further payment of Rs. 5 to Rs. 6 per 1,000 cubic feet of the volume of the cavity made in extracting the ore. The addition to the cost per ton of ore due to this payment depends of course on what proportion of the cavity made was originally occupied by the manganese-ore. The most favourable case is that in which practically the whole of the mass of rock extracted is good ore. A good average value for the specific gravity of Central Provinces ore would be about 4·4 to 4·5. Allowing however for a certain amount of interspaces and friable ore which may be expected even in the most favourable circumstances, it will be preferable to take this figure as 4. One thousand cubic feet of solid ore of specific gravity 4 would weigh about 112 tons. Hence in this case the amount, if paid, for the volume of cavity made would be equivalent to about ¾ anna per ton of ore extracted. As the other extreme we might take a case in which only 1 ton of ore per 1,000 cubic feet of cavity was obtained. This would be equivalent to an addition of about Rs. 5 to Rs. 6 to the cost of extraction of ore per ton. Such ground would not of course be worked unless it were necessary as part of the deadwork of the mine. Five tons of ore per 1,000 cubic feet would be equivalent

to an addition of about 1 rupee to the cost per ton of ore, and 10 tons per 1,000 cubic feet to an addition of about 8 annas. Since under certain circumstances ground of this richness would be worked it will be seen that to the cost of 8 annas to 1 rupee paid per ton of stacked ore, there is another addition, ranging from 1 anna to 1 rupee per ton, to be made for the volume of cavity made in winning the ore. This gives a total of 9 annas to 2 rupees as the amount per ton of ore extracted actually paid to the contractor. This payment by volume of cavity made is more generally applied to detrital deposits where the proportion of ore to waste is very variable and the ground is soft so that the cavities can be squared up for measurement, than to solid ore-bodies, where blasting is necessary, and it is impossible to square up cavities for measurement. In the latter case the 'deads' obtained from the ore-body are added to those obtained from the walls of the deposit and measured with them. At Kumsi in Mysore the payment made is Rs. 20 per 1,000 cubic feet of excavation in the ore-body. This includes breaking up the ore and removing the spoil, but not the ore from the working face; no payment is made on stacked ore.

There are however many other items that come into the cost of a ton of ore. Thus there is the cost of carrying out deadwork. This is sometimes paid on the size of cavity made. In one case in the Central Provinces it ranged from Rs. 35 to Rs. 60 per 1,000 cubic feet of cavity made, according to the nature of the rock to be quarried. In Sandur Rs. 20 per 1,000 cubic feet of cavity is paid for all-round earth-work. In many cases, however, the deadwork is paid for according to the volume as measured in tubs or stacks. The rates for this may be put at Rs. 6 to Rs. 50 per 1,000 cubic feet according to nature of rock being quarried, the lower rates (6—15) being the more usual. It is of course not possible for me to calculate what addition this makes to the cost per ton of ore. It all depends on the amount of deadwork carried out. In cases when the working is carried out on the principle of taking out all the easily-won ore and neglecting all deadwork, except that absolutely necessary for the winning of the ore actually being extracted, this charge is very small. But when the management show any foresight and keep the future life of their deposits in view, doing a considerable amount of deadwork concurrently with the work of winning the ore, this addition may be considerable. There is also the cost of mining tools, such as drills, hammers, crowbars, and shovels, and plant, such as ropeways, inclines, rails, and pumping machines, to be taken into account; and also the upkeep of the mining establishment and local offices. It is not possible for me

to give the figure that should be added to the foregoing to give the true cost of putting a ton of ore on the stacks ready for despatch from the mine. The total costs of mining (including establishment) are, however, placed by various men engaged in the manganese-mining industry at Rs.1-8 to Rs. 3 per ton, and in exceptional cases as low as Rs.1 to Rs.1-4, or as high as Rs. 3-8 to Rs. 4, per ton. From these figures we can deduce that the cost of deadwork, mining plant and tools, and administration, is equivalent to an average addition of about 1 rupee per ton, in some cases falling as low as about 8 annas and in others rising as high as Rs.1-8.

The figures given above apply only to the Central Provinces. I do not know what the total mining costs are for Jhábua, but I should think they are about equal to the lower value for the Central Provinces, say to about Rs.1-4 to Rs.1-8 per ton. In Vizagapatam on the other hand the costs of mining are probably sometimes about the same as in the Central Provinces; but they must often be considerably greater, especially at such a mine as Kodur. For there, although labour is cheaper, such a large amount of deadwork has to be done per ton of ore won, and such a lot of expensive pumping, apart from the distance the ore has to be carried up out of the pit, that I should not think the cost per ton can be less than Rs. 4 to Rs. 5. At some of the other deposits the cost may be a little less; but probably the usual total cost per ton can be fairly put as ranging from Rs. 3 to Rs. 6. The actual rate paid to the contractors I ascertained, when in the district in 1904, to be Rs. 15 per 1,000 cubic feet of ore won, and Rs. 6 to Rs. 15 per 1,000 cubic feet of cavity made. Though these rates are considerably less than those paid in the Central Provinces, yet it must be remembered that the proportion of ore to cavity made is usually much less than in the Central Provinces. In Mysore the total costs of mining may be put at Rs. 2 to Rs. 3-8, averaging about Rs. 2-8. In Sandur they probably work out at about Rs. 3.

Cost of transport to the railway.

All things considered, the cost of mining (including administration) noticed in the foregoing section is small in comparison with the total freight or transport charges incurred by the time the ore reaches the smelting centres. The first freight charge is that of transporting the ore from the mine to the railway. When the industry first started all this transport was effected by means of bullock-carts. These carry from $\frac{1}{2}$ to $\frac{3}{4}$ of a ton, according to the size of the cart, and the extent to which the cartman likes to have his bullocks loaded up. The cost of bullock-cart transport varies consider-

ably in different parts of India, and, moreover, is even in one district subject to considerable fluctuations, according to the season, the price rising whenever there is an increased demand for carts for agricultural purposes, such as for carrying country produce, *e.g.* cotton or grain. In addition to this there is a general tendency to an elevation of rates whenever there are several companies operating in the same area, and a consequent competition to secure the means of transport. The following table gives a few rates obtaining between different mines and the railway. It must be remembered, however, that they only express general average values and that at certain times they may be somewhat wide of the true values :—

TABLE 47.

Rates per ton for carting manganese-ore.

Area.	Deposit from which carted.	Railway station to which carted.	Rates for whole distance.	Average rates for whole distance. [1]	Distance in miles.	Annas per mile of distance.
Bengall .	Gitilpi .	Chakardharpur.	Rs. 3-12	Rs. 3-12	17	3·53
	Tutugutu .	Do.	Rs. 6-4	Rs. 6-4	20	5·00
Central Provinces.	Beldongri .	Salwa .	12 annas	12 annas	7	1·71
	Mansar .	Kámthi .	Rs. 2 to 2-8	Rs 2-8	15	2·67
	Kándri .	Do.	Rs. 2-8 to 4	Rs. 3	17	2·82
	Kodegáon	Nágpur .	Rs. 3-4 to 3-14	Rs. 3-8	22	2·54
	Junawáni .	Do.	Rs. 3-8 to 5	Rs. 4	23	2·78
	Kachi Dhána	Chhindwára	Rs. 9	Rs. 9	30	4·80
Sandur .	Kannevihalli	Tornagallu	Rs. 3-8	Rs. 3-8	17	3·29
Vizagapatam.	Garbhám .	Garividi .	Rs. 1-4 to 2	Rs. 1-10	10	2·60[2]
Mysore	Kumsi .	Shimoga .	Rs. 6	Rs. 6	20	4·30
	Kárkurchi	Bábasandra	Rs 1-6.	Rs. 1-6	9½	2·32

[1] These rates seem abnormally high; the cost of carting iron-ore from Turámdih (4½ miles) and Hakigora (9 miles) to Kálimati station in quite another part of the Singhbhum district works out, however, at 4·5 annas per ton-mile.

[2] Mr. Crawshaw tells me that the rates paid for carting work out at about 2 annas a ton-mile on Local Fund roads, and 2½ annas on cross country tracks.

From the foregoing table it will be seen that the most customary rate in the Central Provinces for the carting of manganese-ore is about $2\frac{1}{2}$ to $2\frac{3}{4}$ annas per ton-mile; but that in the case of deposits very near the station, like Beldongri, the tendency is for the rate to be lowered; and that when the deposit is situated at a considerable distance from the railway, the tendency is for the rate to increase, as in the case of Kachi Dhána; though it must be noted that a portion of the excessive rate in this case is due to the steep ascent up the ghâts on the way to Chhindwára, and to a steep descent and ascent in crossing the Kanhán river. The carting is usually done by contract in the Central Provinces, and the carting rates include the cost of loading the carts at the mines and the stacking of the ore at the railway station. In addition to this a charge of 1 to $1\frac{1}{2}$ annas is incurred in loading the ore into railway wagons.

In the Central Provinces, however, bullock-cart transport is to a large extent being superseded by the construction of light tramways or railways. At present there are two such tramways constructed by the Central India Mining Co., Ltd. One of them, in the Nágpur district, joins the Mánegáon, Mándri, Panchála, Kácharwáhi, and Lohdongri deposits to the Bengal-Nágpur Railway at Thársa, the total distance from Mánegáon to Thársa being $13\frac{1}{2}$ miles; the other, in the Bhandára district, connects the western Bhandára deposits, such as Chikhla, Kosumbah, and Sukli, to the Bengal-Nágpur Railway at Tumsár Road, the total distance from Kosumbah being about 34 miles. These two lines are of 2-foot gauge. On the Nágpur-district line the ore was at first carried by hand-tramming in trains of a few trucks each. But now this line, as well as the Bhandára line, has been converted to steam traction and the ore is hauled in trains of 25 to 30 trucks at a time, each truck holding 1 to 2 tons according to size. The Bálághát deposit has been connected directly to the $2\frac{1}{2}$-foot-gauge branch of the Bengal-Nágpur Railway known as the Sátpura Railway, by a short line of 2 miles' length. The last connection is the broad-gauge branch of the Bengal-Nágpur Railway running out to Rámtek, with a siding to Mansar and Kándri, a total distance of about 17 miles. This was completed and opened to traffic during 1908. Another line that would further decrease the need of bullock-cart transport is the proposed extension of the Sátpura Railway from Nágpur to Chhindwára; another proposed branch of the Sátpura system is a line from Mandla to Bilaspur, passing through Baihar in the Bálághát district, from which place a siding could be run out to Ukua.

It is also proposed to run out a branch of the Bengal-Nágpur Railway from Tumsar Road to Katangi in western Bálághát, along the same route as the Central India Mining Company's steam tramway: whilst there is also a desire for a line joining Katangi to Bálághát, but such a line has not yet been sanctioned.

In Jhábua in Central India, Messrs. Kiddle, Reeve and Company have, nearly from the first, obviated the necessity of bullock-cart transport by the construction of a light 2-foot gauge line from Kájlidongri to Meghnagar on the Godhra-Ratlám Railway, a distance of 5½ miles. This was at first worked by hand-tramming, but has, I believe, been now converted for steam traction. In the Sandur area a 5½ miles' extension of the metre-gauge Southern Mahratta Railway has been constructed from Mariyamanhalli on the Hospet-Kottur Branch of the Southern Mahratta Railway to the unloading station of the aërial ropeway at the foot of the hill near Rámandrug; whilst there is a proposition, now under consideration, of making further extension of about 20 miles' length to Kamátaru in the southern part of the Sandur Hills; this will possibly be on the assisted-siding principle, by which the railway company supplies the permanent-way material and the mining company bears the entire cost of construction. The New Mysore Manganese Co., Ltd., is putting down a 2-foot gauge line for steam traction from the Kumsi mines to Shimoga Railway Station, a total distance of 20 miles, of which 10 miles had still to be constructed in September 1907. If this process continues it is probable that in the course of the next five years most of the important deposits will be directly connected to the railway system of the country by some sort or other of light feeder line. This will of course set free a large number of bullock-carts, which, as before the start of the manganese industry, can be used in the fields, and for the carriage of country produce in cases where it is not also carried on the new railway lines. A large number of carts have been specially made for the manganese-ore traffic. But the owners of these will not have much cause of complaint at the disappearance of their lucrative occupation, for their profits have in most cases probably paid several times over for the cost of the carts. This diminished demand for carts may have the advantage, as considered from the mine owner's point of view, of causing the unemployed cartmen to take to mining, and so lessening the labour difficulty.

As regards the cost per ton-mile of carrying ore on these mining lines I have little information. But I should think it would not average more than ½ an anna, including both the costs of working, interest on capital

expenditure, and depreciation. In some cases it might rise as high as one anna, and in others be even as low as $\frac{1}{4}$ anna (3 pies). But it is not probable that the lower figure will often be approached, for the rate charged on the broad-gauge line of the Bengal-Nágpur Railway is $\frac{1}{10}$ pie per maund per mile, or 2·722 pies per ton-mile.

Cost of railway transport to the port of shipment.

The minimum rate that the railways are allowed to charge for the carriage of such freights as coal and manganese-ore is $\frac{1}{10}$ of a pie per maund per mile, equivalent to 2·722 pies per ton-mile.[1] The cost of railing the ore to the ports works out on this basis as follows :—

TABLE 48.

Rates for the carriage of manganese-ore to the ports over Indian railways.

Railway station to port.		Area tapped.	Province.	Mileage from railway station to port.	Freight per ton.
					ℛ a. p.
Chámpáner Road	to Bombay	Panch Mahál district.	Bombay	270	3 13 3
Meghnagar	to Bombay	Jhábua State.	Central India	361	5 1 11
Bálághát	to Bombay	Bálághát district.	Central Provinces.	627	8 14 3
Tumsar Road	to Bombay	Bhandára and Bálághát districts.	Central Provinces.	570	8 1 4
Chhindwára	to Calcutta	Chhindwára district.	Central Provinces.	783	11 1 7
Nágpur	to Bombay	Nágpur district.	Central Provinces.	520	7 6 0
Kámthi	to Bombay	Nágpur district.	Central Provinces.	529	7 8 0
Salwa	to Bombay	Nágpur district.	Central Provinces.	535	7 9 4
Thársa	to Bombay	Nágpur district.	Central Provinces.	543	7 11 2
Nágpur	to Calcutta	Nágpur district.	Central Provinces.	701	9 15 0
Kámthi	to Calcutta	Nágpur district.	Central Provinces.	692	9 13 0
Garividi	to Vizagapatam	Vizagapatam district.	Madras	56	0 12 8

[1] One ton taken as equal to 27·22 maunds.

The Southern Mahratta Railway has not accepted the minimum rate of $\frac{1}{10}$th pie per maund per mile, and fixes the rates for each station separately. The rates quoted by this company consist of two portions, freight charges, and wharf dues at Mormugáo, to which port all the ore carried by this railway is taken. The freight rates from the various exporting stations to the port of Mormugáo are as follows:—

TABLE 49.

Rates for the carriage of manganese-ore to Mormugáo by the Southern Mahratta Railway.

Railway Station.	Area tapped.	Province.	Mileage from railway station to Mormugáo.	Freight per ton.
				R a. p.
Rámanamalai (Rámandrug)	Sandur Hills	Madras	253	5 12 3
Tornagallu			251	5 7 9
Harihar	Chitaldrug district.	Mysore.	223	5 1 0
Chik Jájur			260	5 5 6
Holalkere			266	5 7 9
Tarikere	Shimoga district.		317	5 10 0
Benkipura			330	5 12 3
Shimoga			340	5 12 3
Bánasandra	Tumkur district.		359	6 3 0

At the rate of $\frac{1}{10}$th pie per maund per mile the freights from Rámandrug and Shimoga to Mormugáo would be Rs. 3-9-5 and Rs. 4-13-1 respectively.

On the Bengal-Nágpur Railway steel trucks are used for the carriage of manganese-ore; they hold from 14 to 16 tons of ore each. It used to be the custom to run each truck on to a weigh-bridge to ascertain the exact amount of ore loaded into it. But the traffic has now grown to such an extent that it is a matter of considerable inconvenience to do this for every truck. Consequently it has been decided to load by measurement. Experiments have been made in which a large number of wagons loaded up to a certain mark, so that the volume of loose ore

contained in each is known, have been weighed, and a figure fixed for the average relation between volume and weight of the ore. In the case of the Central Provinces Prospecting Syndicate it has been decided that the correct figure is 16 cubic feet to the ton. And to allow for any losses, they are allowed by the railway to load on the assumption that $16\frac{1}{2}$ cubic feet of ore go to the ton. For each company's ore the figure has to be determined separately, but it is seldom that the figure exceeds 17 cubic feet to the ton. In cases of operators railing only small quantities of ore actual weighing is still resorted to. For loading by volume a horizontal chalk line is drawn round the inside of each wagon at the height above the bottom of the wagon to which it has to be loaded in order to take the amount of ore the truck is allowed to carry. This loading is done from the ore stacks at the station by men, women, and children. The cost of this is about 1 to $1\frac{1}{2}$ annas per ton, and is paid by the mine operators. In cases where the ore has to be transferred from wagons on the narrow gauge to wagons on the broad gauge, the transferment is done at the expense of the railway. Such is the case at Gondia, where ore carried from Bálághát and Chhindwára on the Sátpura Railway ($2\frac{1}{2}$-foot gauge) has to be transferred to broad-gauge wagons. For the carriage of the Central Provinces ore to Bombay whole trains are usually employed.

Cost of handling at the port of shipment: Bombay.

When the ore-train arrives at Bombay the ore is dumped and stacked on the storage ground at Malet Bandar; or if a ship is waiting to be loaded the ore is carted or trammed at once to the dock side. Here it is dumped in heaps on the edge of the wharf and transferred to the ship by means of buckets attached to the ship's slings or derricks. To obviate the delay and uncertainty involved in carting the ore from the storage ground to the dock, a dock tramway has been constructed from the storage ground at Malet Bandar to the dock. The dumping at the storage ground is usually necessary; for it is necessary to have a stock of ore on hand so that there may be no shortage of ore when a ship is ready to be loaded. The charges per ton usually incurred at Bombay [1] are as follows:—

	A.	*p.*
Unloading wagons and stacking on dump	2	0
Siding charge	2	0
Railing to dock on dock tramway	10	6
Wharfage (including the loading into ships)	8	0
	Rs. 1	6-6

[1] Kindly supplied by the Secretary to the Bombay Port Trust.

When the ore is carted to the dock instead of being railed on the dock tramway, the cost varies from 6 to 10 annas, according to lead and other circumstances. Stacking ground rent at Rs. 7 per 500 square feet is also charged. The third item can sometimes be avoided by arranging to rail the original ore-train into dock a short distance from the vessel. The ore can then be unloaded by Dock Contractors and dumped alongside the vessel. The charges would then be as follows:—

	A. p.
Unloading wagons and dumping by the side of the vessel . .	1-6
Siding charge	2-0
Wharfage	8-0
	11-6

The charges incurred at Bombay vary therefore from 11½ annas to Rs. 1-8, the latter limit being given to allow for the fact that there are often expenses incurred by the shippers that are not included in the foregoing figures. Rs. 1-4 can perhaps be taken as an average figure.

Calcutta.

Manganese-ore railed to Calcutta has to be ferried across the River Hughli from Shalimar to the Kidderpore Docks in the Bengal-Nágpur Railway steam ferry-boats, which carry 23 railway wagons each. This charge is apparently included in the cost of railing the ore from the forwarding station to the docks. The charges per ton incurred at the Docks are[1]:—

	A. p.
Dumping on wharf pending shipment	2-0
Shipping charge	6-6
River due	1-6
	10-0

As extra charges there are:—

If shipped at night	1-0
Removal if incurred	4-0

Rent, if incurred, Rs. 4 per cottah per month.

The dumping charge may be avoided if the ore does not have to wait pending shipment. The Calcutta charges vary therefore from 8 to 15 annas, with an average figure of about 10 annas.

Vizagapatam.

At the Port of Vizagapatam the railway siding is on the beach, where the ore is dumped from the railway wagons; from there it is taken by a short lead to the surf boats and carried out in these to the steamer lying

[1] Kindly supplied by the Secretary to the Commissioners of the Port of Calcutta.

outside the surf. An occasional loss of ore is suffered in this process through the capsizing of a surf-boat. In the case of one company the shippers charge Rs. 1-2 per ton from railway wagons to ship; in addition to this there are port dues of 2 annas a ton to be paid.

Mormugáo.

At the port of Mormugáo the Southern Mahratta Railway[1] has charge of the shipping arrangements. Consequently the Railway Company quotes not only freight rates from the forwarding station, but also the charges incurred at the Port, grouping the latter under the heading of wharf dues. The total of freight rates *plus* wharf dues include the loading of the ore into trucks at the forwarding station, unloading it at the stacking ground at Mormugáo Harbour, loading again into trucks and putting the ore into trays alongside the steamers; they do not include, however, the cost of hauling on board or distributing the ore in the holds of the steamers. The cost of hauling on board comes to 1 anna per ton, and the trimming in the hold is included in the steamer freight rates. The wharf dues charged by the Southern Mahratta Railway are now Rs. 1-2, but were formerly only 9 annas per ton. Including the 1 anna for loading on board the total charges now incurred at the Port of Mormugáo are Rs. 1-3.

Cost of shipping to Europe and America.

The ocean freight rates charged for carrying manganese-ore from Indian ports to those of England, the Continent, and America, depend on whether it is shipped as whole cargo, or as dead weight forming only a portion of the cargo. From Bombay whole cargoes are often sent, but part cargoes only are shipped from Calcutta. The rates from Bombay to England and the Continent, are stated[2] to have been, in August 1906, 16 shillings for whole cargoes and 14 to 15 shillings for part cargoes; whilstt he ordinary variation in freight rates for manganese-ore from Bombay is between 15 and 20 shillings per ton to England and the Continent, and 16½ to 20 shillings to America. A fair average rate is probably about 16 shillings or Rs. 12 to England and the Continent, and 18 shillings or Rs. 13-8 to America. At present (September 1907), however, the rates are up and are stated to be 17½ shillings for part cargoes and 19 for full cargoes to the United Kingdom, and 20 shillings for full cargoes to America. In Calcutta there is a liner's conference, which has fixed the minimum rate of freight on ore

[1] I am indebted to the Traffic Manager, S. M. R., for the following information.

[2] C. E. Low, Gazetteer of the Bálághát District, page 231, (1907).

to English and Continental ports at 15 shillings a ton, though it has been as low as 10 shillings for part cargoes. It is said, however, that this rate (15*s.*) is not often obtainable unless steamers are short of other cargo, and that 17 shillings and 6 pence is a fair average rate. This is equivalent to Rs. 13-2 per ton.

The rates from the port of Vizagapatam are usually about the same as those from Calcutta. They are now (September 1907) up and said to be as high even as 22 shillings for full cargoes, and a little less for part cargoes when such are obtainable. These rates probably apply to ore shipped to America, however, and would be less for United Kingdom and Continental ports.

The rates from Mormugáo vary from 12 to 20 shillings according to the state of the freight market and were stated to be 18½ to 20 shillings in August 1907, for full cargoes to United Kingdom ports.

Insurance.

It is also customary to insure the cargo against loss. This is reckoned by adding 10 per cent. to the *c.i.f.* sale price of the ore, and taking ¾ per cent. of this value. On a 50 per cent. ore the marine insurance would therefore vary from 3¾ annas to 6½ annas per ton, according as the *c.i.f.* value of the ore varied from 9 to 16 pence per unit. In the estimate (page 486) of the total cost of putting the ore *c.i.f.* on the market I have included this charge in the ocean freight.

Destination charges.

When the ore arrives at the port of destination there are various other charges to be incurred before it can be delivered to the buyers. These may include port dues, unloading from ship, costs of sampling and assaying, and brokerage and agency at destination. The only figure I have for the total of these charges is Rs. 2 per ton. The detailed charges as given to me by Mr. Aubert for average cases are the following :—

	Pence.
1. Check weighing by buyers on arrival	1
2. First sampling and analysis paid by sellers (the buyers also pay the same amount, if they haven't their own men)	6
If the sellers' and buyers' analyses differ by more than 1 per cent., a reference analysis is made by a recognized firm of analysts.	
3. Home agents commission, generally 1½ per cent., on *f.o.b.* price of ore, which would vary from 3¾ to 9 pence on a 50 per cent. ore according as the *f.o.b.* price varied from 5 to 12 pence, corresponding to a *c.i.f.* price of 9 to 16 pence, assuming an average freight of 17 shillings	3¾—9

	Pence.
4. Brokerage (sometimes) of 1 per cent. on *c.i.f.* price = 4½ to 8 pence on a 50 per cent. ore, according as *c.i.f.* price varies from 9 to 16 pence	0–8
5. Telegrams, and sundry expenses of the deal	3
Total .	13¾–27

Hence the total of these charges works out as ranging from 14 annas to Rs. 1-11, with an average value of about Rs. 1-4.

When these expenses and all those mentioned in the previous paragraphs have been met by the sellers, then the ore is said to be delivered *c.i.f.* to the buyers.

Total costs of mining manganese-ore in India and delivering it *c.i.f.* at foreign ports.

Largely from the data given in the foregoing paragraphs I have drawn up the statement given in table 50 of the limits and average cost of ore derived from five of the producing areas, namely the Central Provinces, Jhábua in Central India, Sandur and Vizagapatam in Madras, and Mysore. The figures of most importance are those relating to Central Provinces ore exported *viâ* Bombay. For not only did about ⅔ of the Indian manganese ore exports for 1906 pass through this port, but 85 per cent. of this amount was derived from the Central Provinces, from which about 60 per cent. of the Indian production now comes. These figures are also the most accurate. It will be seen that the cost of exporting Central Provinces ore *viâ* Calcutta is considerably higher than for Bombay. This is due to heavier transport charges, owing partly to the longer railway lead to Calcutta than to Bombay, and partly to the unfavourable situation, with regard to the railways, of the deposits the output of which goes to Calcutta. Of the figures for Jhábua, the first two items are guesses; the third is, as in the case of all the other producing areas, calculated on the $\frac{1}{10}$th pie per maund per mile basis; whilst the other charges are assumed to be the same as for Central Provinces ore passing through the port of Bombay. The figures for Vizagapatam are also mostly guessed, but are not likely to be very wide of the mark. The figures for Sandur and Mysore have about the same degree of accuracy as those for the Central Provinces. I have no details about the ore exported from the Panch Mahâls district, Bombay; but I should think that this ore must cost about the same, or a little more, delivered *f.o.b.* at Bombay, as that of Jhábua. From this table we can

TABLE 50.

Summary of costs per ton of delivering Indian manganese-ore c. i. f. at English and Continental ports.

	FROM THE CENTRAL PROVINCES.				FROM JHÁ-BUA.	FROM VIZAGAPATAM DISTRICT.		FROM SANDUR.		FROM MYSORE.	
	Viâ Bombay.		*Viâ* Calcutta.		*Viâ* Bombay.	*Viâ* Vizagapatam Port.		*Viâ* Mormugáo.		*Viâ* Mormugáo.	
	Limits.	Average.	Limits.	Average.	Average.	Limits.	Average.	Limits.	Average.[1]	Limits.	Average.[2]
	Rs. a. Rs. a.	*Rs. a.*	*Rs. a. Rs. a.*	*Rs. a.*	*Rs. a.*	*Rs. a. Rs. a.*	*Rs. a.*	*Rs. a. Rs. a.*	*Rs. a.*	*Rs. a. Rs. a.*	*Rs. a.*
Cost of mining (labour, tools, plant, and administration).	1—0 to 4—0	2—12	1—0 to 3—0	2—8	2—4	3—0 to 6—0	5—0	2—6 to 3—0	3—0	2—0 to 3—8	2—8
Transport to rail-head . .	*Nil* to 5—0	1—8	3—4 to 10—0	4—0	0—5	*Nil* to 4—0	1—8	0—0 to 3—10	0—0	1—0 to 6—9	6—9
Railway freight . . .	7—6 to 8—15	8—0	9—15 to 11—2	10—0	5—2	0—11 to 1—0	1—4[3]	5—8 to 5—12	5—12	5—5 to 6—3	5—12
Handling at port . . .	0—10½ to 1—8	1—4	0—8 to 0—15	0—10	1—4	1—2 to 1—4	1—4	1—3 to 1—3	1—3	1—3 to 1—3	1—3
Agents' commission . .	*Nil* to 0—4	0—2	0—4 to 0—4	0—4	0—0	*Nil* to 0—4	0—4	0—4 to 0—4	0—4	0—4 to 0—4	0—4
∴ Cost *f. o. b.* at port . .	9—0½ to 19—11	13—10	14—15 to 25—5	17—6	8—15	4—13 to 12—8	9—4	9—5 to 13—13	10—3	9—12 to 17—11	16—4
Ocean freight (with insurance)	9—0 to 15—0	12—0	10—0 to 13—2	13—0	12—0	12—0 to 16—8	13—8	9—0 to 15—0	12—0	9—0 to 15—0	12—0
Destination charges . .	0—14 to 2—0	1—4	0—14 to 2—0	1—4	1—4	0—14 to 2—0	1—4	0—14 to 2—0	1—4	0—14 to 2—0	1—4
∴ Cost *c. i. f.* at destination .	21—8 to 36—11	26—14	25—13 to 40—7	31—10	22—3	17—9 to 31—0	24—0	19—3 to 30—13	23—7	19—10 to 34—11	29—8

[1] This average applies to Rámandrug.

[2] This average applies to Kumsi. The second item is higher than it should be. At 4 annas a ton-mile, the normal rate for this part of Mysore, the carting cost from the Kumsi mines to Shimoga, 20 miles, would be Rs. 5. When the steam tramway is finished this item should be considerably reduced. The cost for the other Mysore deposits is probably less than for Kumsi, owing to the shorter railway lead, and might be put at an average of about 25 to 26 rupees per ton.

[3] In addition to railway freight there is a terminal charge of As. 5 per wagon, bringing the average rate up to about Rs. 1-4.

give the following abstract of the average cost of delivering Indian manganese-ore *c.i.f.* at English and Continental ports :—

TABLE 51.

Average cost of Indian manganese-ore delivered c.i.f. at English and Continental ports.

Area from which derived.	Port from which exported.	Average cost per ton.
		Rs. *a.*
Central Provinces	Bombay	26 14
Ditto	Calcutta	31 10
Jhábua, Central India	Bombay	22 3
Vizagapatam, Madras	Vizagapatam	23 7
Sandur, Madras	Mormugáo	23 7
Mysore	Mormugáo	29 8

Comparison of the costs of production of Brazilian, Russian and Indian ores.

It is a matter of some interest and importance to Indian manganese miners to know approximately the costs at which the ores of the two most important manganese-producing countries besides India, namely Brazil and Russia, can be put on the same markets. In table 52 I give figures of costs of production of manganese-ore in Russia and Brazil, alongside similar figures for Indian ore from the Central Provinces and Vizagapatam. The figures for Brazil are taken from a paper by Léon Demaret entitled ' Les principaux gisements des Minerais de Manganèse du Monde '[1]. He gives the figures for the various items of cost incurred in putting the ore *f.o.b.* at Rio Janeiro in milreis Now the rate of exchange between

[1] *Annales des Mines de Belgique*, X, pp. 843,886, (1905).

the coinage of Brazil and that of America and European countries is subject to considerable fluctuations. When the rate of exchange is very high, then the cost of putting the ore *f.o.b.* at Rio is so high that unless the price per unit of manganese-ore on the American and European markets is also abnormally high it is very difficult to work the Brazilian ore at a profit; on the other hand in times of low exchange the profits on the Brazilian ore may be very large. For this reason I have converted the various items expressed in milreis into Indian currency, first on a basis of a rate of exchange of 1 milreis = 7 pence, *i.e.*, 7 annas, and secondly on a basis of 1 milreis = 14 pence, *i.e.*, 14 annas. The first of these is a low rate of exchange and the latter a high rate. In the case of Russia, I have given two different estimates of the costs of putting the ore *c.i.f.* at United Kingdom ports. That of Demaret being of later date may be the more accurate; but it must be remembered that it also relates to the time before the disturbances that so upset the manganese industry in the Caucasus. An estimate by W. Venator [1] gives the cost of Caucasian ore delivered *c.i.f.* in England as 49 francs, which equals Rs. 29-2-4, at £1 = 25·22 fr. This agrees closely with Drake's figure. It is possible, now that the conditions have become quieter, that the rates may be considerably different on account of changes of labour or transport conditions.

From the table it will be seen that in times of low exchange in Brazil it costs about the same amount to put the Brazilian ore on the European markets, as that of Vizagapatam; whilst in times of high exchange the cost of putting the Brazilian ore on the market may be considerably higher than for either Russian or Indian ore. The average cost of putting Russian ore on the market is evidently approximately the same as for that of the Central Provinces, and higher than for that of Vizagapatam.

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1 'Die Deckung des Bedarfs an Manganerzen', *Stahl und Eisen*, XXVI, p. 71, (1906).

TABLE 52.

Comparison of cost of delivering Brazilian, Russian and Indian manganese ore c. i. f. at London.

	BRAZIL (Minas Geraes).						RUSSIA (Caucasus).						INDIA.					
	According to Demaret[1] (1905).	At 1·000 milreis = 7 annas			At 1·000 milreis = 14 annas.		According to Demaret[2] (1905).			According to Drake[3] (1898).			Central Provinces *vid* Bombay.			Vizagapatam.		
	Milreis.	*Rs.*	*a.*	*p.*	*Rs.*	*a.*	*p.*	*Rs.*	*a.*	*p.*	*Rs.*	*a.*	*p.*	*Rs.*	*a.*	*p.*	*Rs.*	*a.*	*p.*
1. Extraction and administration	[4] 14·000	6	2	0	12	4	0	2	6	5	2	14	0	2	12	0	5	0	0
2. Transport to railway	2·000	0	14	0	1	12	0	2	4	0	2	3	6	1	8	0	1	8	0
3. Loading into railway wagons	0·200	0	1	5	0	2	10							(*a*)			(*a*)		
4. Loading and transhipment charges between Tchiatoura and Poti								1	0	0	1	2	0						
5. Railway transport to port of shipment	10·140	4	7	0	8	14	0	8	13	4	11	14	0	8	0	0	0	13	0
6. Handling at port	1·500	0	10	6	1	5	0	1	7	6	1	6	9	1	4	0	1	2	0
7. Royalty to state	(*b*)													0	4	0	0	4	0
8. Royalty to proprietor	1·000	0	7	0	0	14	0												
9. Rent to state								0	8	7									
10. Agent's commission														0	4	0	0	4	0
Total cost *f. o. b.* at port	28·840	12	9	11	25	3	10	16	7	10	19	8	3	14	0	0	8	15	0
11. Ocean freight to London		9	0	0(*c*)	9	0	0(*c*)	10	1	2(*c*)	9	13	9	12	0	0	13	8	0
12. Destination charges		1	6	0	1	6	0							1	4	0	1	4	0
Total cost *c.i.f.* at London.		22	15	11	35	9	10	26	9	0	29	6	0	27	4	0	23	11	0

[1] *Annales des mines de Belgique*, X, p. 843, (1905).
[2] *Loc cit*, p. 886.
[3] *Trans. Am. Inst. Min. Eng.*, XXVIII, p. 207, (1898).
[4] Includes taxes.

(*a*) Included in item 2.
(*b*) Probably included in item 1.
(*c*) Limits Rs. 6 to Rs. 15.

Royalty.

In the foregoing figures of the cost of delivering manganese-ore at the ports of the countries where it is to be used, I have not included

royalty (except in table 52). According to a resolution of the Government of India—Department of Revenue and Agriculture, Geology and Minerals, No. 18—17-2, dated Simla, 20th May 1899—grantees of prospecting licenses and mining leases shall pay a royalty on all minerals won, at the rates specified in Schedule C attached thereto. Manganese-ore comes under the following section of this Schedule :—

'Copper, tin, lead, or other metals .	2½ per cent. on the sale value at the pit's mouth or on the surface, of the dressed ore or metal, convertible at the option of the lessee to an equivalent charge per ton to be fixed annually for a term.'

This resolution applies to the grant of licenses and leases only in British India. In the Native States a fixed royalty irrespective of market price of the ore is usually arranged when a prospecting license or mining lease is granted. The rates prevailing in various States are as follows :—

TABLE 53.

Royalty, in annas per ton, levied in certain Native States and Zamindári Lands.

	Annas.
Jhábua State, Central India	4
Mysore State	6+2½% on profits over 10% of capital.[1]
Sandur State, Madras	6
The Vizianagram Samasthánum, Madras ..	4

In the Central Provinces, however, where the deposits are all in British India, the rates are levied on the principle of 2½ per cent. on the wholesale value of the ore at the pit's mouth. In 1903 the rate levied was 1½ annas per ton. This was decreased to 1 anna per ton in 1904 when the price of manganese-ore was rapidly approaching its minimum value. During 1906 the rate was again raised to 2 annas, and later in the year to 4 annas per ton, this rise of royalty corresponding with a rise in the price per unit of manganese-ore. It is obvious, however, that the elevation of the royalty in 1906 was not nearly enough, even on the 2½ per cent. basis, if it was to have kept pace with the rise in the price of the mineral. When the price of manganese-ore per unit rises above 11 pence, then the profits of the operators increase enormous-

[1] There is a proposal on foot to consolidate this to a royalty of 10 annas per ton.

ly, and it is certain that a substantial increase in the royalty levied by Government would still leave a very handsome profit to the operators. [The royalty levied in the Panch Mahâls district of Bombay is 1½ annas a ton.]

In any case, however, a sliding scale of royalties should be drawn up, so as to admit of the alteration of the royalty from time to time according to the price of manganese-ore per unit, the royalty levied being on a basis of 2½ per cent. of the pit's mouth value of the mineral. In constructing this scale of royalties it might seem as first sight as if it should be so drawn up as to take into account the differences in the quality of the ores from different deposits, the different distances of the deposits from the rail, the differences in the cost of winning the ores, and the fact that contracts for the supply of ore are often made a year or two ahead. This would, however, be so exceedingly complicated and so difficult of application, and would lead to so many disputes, and also to invidious distinctions between different firms, that it is desirable to avoid it. The average percentage of manganese in the ores exported from the Central Provinces can be taken as about 52. Hence if the royalty be fixed on the assumption that all ores are 50 per cent. ores, it would on the average be in favour of the operators. Hence, for the construction of what I think would be a fair schedule of royalties, I have taken a basis of 50 per cent. of manganese in the ores, and the quotations of the price per unit of first-grade ore as given in the *Mining Journal*, London.

For the calculation of this table of rates it is necessary first to calculate what would be the pit's mouth value of the ore at the various prices per unit. Judging from the figures given in table 50 on page 486, a very fair average value for the cost of delivering the manganese-ore at the ports of destination would be Rs. 26-14, this being the value for the Central Provinces ore exported *viâ* Bombay. For the purposes of calculation Rs. 27 can be taken. Now the difference between this value and the price per ton the ore will fetch at the contract price when landed at the port of destination is the actual profit made by the operators. The true value at the pit's mouth is obtained by adding to this profit the cost per ton of quarrying or mining the ore and stacking it on the mine. The average value for this is Rs. 2-12. Now at a price of 10 pence per unit, the price received per ton of ore is Rs. 31-4. Taking the average cost of delivery *c.i.f.* at the port of destination as Rs. 27, then the profit per ton at this price is Rs. 4-4. Adding to this the cost of mining, Rs. 2-12, the pit's mouth value works out at Rs. 7. The

royalty on this at 2½ per cent. is 2·8 annas or, to the nearest half anna, 3 annas. On this basis I have drawn up the following table :—

TABLE 54.

Royalties in annas per ton leviable on Central Provinces manganese-ore at 2½% on pit's mouth value.

1	2	3	4	5	6	7
Price per unit of first-grade ore.	Value of 50% ore delivered c.i.f. at English and Continental ports.	Profit per ton (figures in column 2 *less* ₹27).	Pit's mouth value (figures in column 3 *plus* ₹2-12, the cost of mining).	Exact royalty leviable at 2½% on pit's mouth value.	Royalty leviable at 2½% (given to nearest half anna).	Royalty leviable at 2½% up to 12 pence a unit and 5% above 12 pence.
Pence.	*Rs. a.*	*Rs. a.*	*Rs. a.*	*Annas.*	*Annas.*	*Annas.*
8	25—0	*Nil.*	2—12	1·10	1	1
9	28—2	1—2	3—14	1·55	1½	1½
10	31—4	4—4	7—0	2·80	3	3
11	34—6	7—6	10—2	4·05	4	4
12	37—8	10—8	13—4	5·30	5½	5½
13	40—10	13—10	16—6	6·55	6½	13
14	43—12	16—12	19—8	7·80	8	16
15	46—14	19—14	22—10	9·05	9	18
16	50—0	23—0	25—12	10·30	10½	21
17	53—2	26—2	28—14	11·55	11½	23
18	56—4	29—4	32—0	12·80	13	26

It seems to me that the best way of levying royalty according to this schedule would be to fix it on the first of January every year, on the basis of the true mean of the prices quoted in the Mining Journal during the preceding year. As, however, the average price of first grade ore during one year may be considerably higher or lower than during the previous year, it would be necessary to bring about an adjustment at the end of the year between the royalties actually paid by the operators and the amounts payable on the basis of the average price during the year under consideration. Thus if the rate had been fixed at the beginning of a given year on the basis of an average price of 11 pence per unit during the previous year, and at the end of this given year it was found that the average rate had risen to 13 pence, then the mine operators should be required to pay to the local government an amount per ton equal

to the difference between the royalties that would have been leviable at the two different average prices per unit of manganese-ore ; whilst if the average rate had fallen during the year to 10 pence, then it would be necessary for the Government to make a refund of the difference per ton between the royalties leviable at the two different rates. This might be actually returned by the Government in cases where the operators had actually ceased to work, or set aside towards the payment of the royalties leviable during the ensuing year. This sounds rather complicated, but in practice it would probably prove easy of application, and satisfactory to the mine operators.

CHAPTER XXIV.

ECONOMICS & MINING—*continued.*

Valuation and Chemical Composition of Manganese-ores.

Valuation of manganese-ores—Mining Journal prices—Schedule of the Carnegie Steel Company—Requirements made less stringent during 1906—Special prices—Valuation of ores for chemical purposes—Nomenclature of manganese-ores and manganiferous iron-ores—Ferruginous manganese-ores.

Tables of analyses of Indian ores—Summary of tables of analyses—Analyses of Indian ores expected by buyers.

Analyses of manganese-ores of the World—Analyses of cargoes of Indian and foreign ores landed at Middlesborough—Analyses of the manganese-ores of the world.

The less important constituents of Indian manganese-ores—Alumina—Baryta—Lime—Magnesia—Potash—Soda—Arsenic—Sulphur—Cobalt and nickel—Copper—Lead—Zinc—Titanium—Combined water—Carbon dioxide.

Valuation of Manganese-ores.

Mining Journal prices.

As has been explained on a previous page, the price per ton of manganese-ore obtained on its delivery *c.i.f.* at the port of destination is subject to great variations according to the price per unit of manganese. On pages 415-6 is given a table showing the fluctuations in the price per unit of manganese for ores of different grades since 1890, as quoted in the Mining Journal. The variations are illustrated by a diagram (fig. 23) on page 417. On pages 447-9 I have considered the relation between the prices of manganese-ore at different times and the Indian output

The prices given in these tables are for the three grades into which manganese-ores are, for commercial purposes, classified :—

1st grade	.. ..	50% Mn. and upwards
2nd grade	.. ..	47—50% Mn.
3rd grade	.. ..	40—47% Mn.

As an example of the way in which the schedule of prices is applied we can take the case of a 52% ore from the Central Provinces in January 1907. The average price at this time was $15\frac{1}{2}$ pence per unit. The price then per ton paid or this ore would be $\frac{52\times15\frac{1}{2}}{12}$=67 shillings and 2 pence per ton = £3-7-2.

In order that an ore should be subject to the application of the scale of prices given in table 27 on page 415 it was formerly necessary that it should not contain more than 10% of silica and 0·10% of phosphorus. [These rates may be considered as those applied to ore delivered in the United Kingdom.]

Schedule of the Carnegie Steel Company.

In the United States, according to the 'Mineral Industry' for 1905, published in 1906, the schedule is fixed by the Carnegie Steel Company. The ore must not contain more than 0·1% of phosphorus, nor over 8% of silica; deductions are made from the price of the ore of 15c. per ton for each 1% of silica in excess of 8% and of 1c. per unit of manganese for each 0·02% of phosphorus in excess of 0·1%. The price per unit of manganese given in this publication is as follows:—

Over 49% of Mn.	..	28 cents.
46—49% of Mn.	..	27 „
43—46% of Mn.	..	26 „
40—43% of Mn.	..	25 „

Ore containing less than 40% of manganese, or phosphorus or silics in excess of the above limits, is sometimes subject to acceptance or refusal at the buyer's option. An additional price per unit of iron present in the ore is sometimes paid by the steel-makers; but the practice as regards this constituent varies. In the 'Mineral Industry' for 1903, issued in 1904, where the price per unit of manganese for ores containing over 49% of this constituent is given as 25c., the price paid by the Carnegie Steel Company for each unit of iron is given as 5c.

Owing, however, to the rise in prices during 1906, and the great difficulties steel-makers are said to have encountered during this year in obtaining the full amounts of ore required, there seems to be a tendency for a slackening in the stringency of the requirements of the steel-makers, especially as regards manganese and phosphorus contents. It is probable that a considerable proportion of these restrictions are not always closely connected with any metallurgical difficulties in the treatment of the ores, but with the desire of the steel-makers to obtain their supplies of manganese-ore at as favourable a price as possible, and to be able to cut down the prices paid whenever possible by levying fines for the presence of a small percentage of a given constituent in excess of what is stated in their schedule of prices. That this is probably the true interpretation of the situation is shown by the fact that during 1906, under the influence of the great

Requirements made less stringent during 1906.

demand for Indian ores, it seems to have been possible to find a market for almost every variety of ore that could be obtained, except the very siliceous ones. There has for some years been a steady demand for the ores of Vizagapatam, ranging in phosphorus from 0·25 to 0·45%, and for the Jhábua ores averaging 0·20% of phosphorus. During 1905 and 1906 a market was also found for Vizagapatam ores containing between 30 and 40% of manganese; and I understand that during 1907 some of the ores from Shimoga in Mysore for which a market was found ran as low as 30% in manganese. The constituent that seems to be of much more importance than the phosphorus as a deleterious constituent is the silica and I do not know of any cases of contracts made for the supply of Indian manganese-ores containing over 10% of this constituent.

According to John Birkinbine[1] the requirements of the steel manufacturers, particularly with regard to the permissible phosphorus, were altered in a schedule issued in the latter part of December 1905. This schedule applies to the Carnegie Steel Company and the Illinois Steel Company.

'Prices are placed on ores delivered in the Pittsburg, Pa., and Chicago, Ill., districts, per long ton, containing not more than 8 per cent silica and not more than 0·25 per cent phosphorus, and are subject to deductions as follows:

'For each 1 per cent in excess of 8 per cent silica there shall be a deduction of 15 cents per ton, fractions in proportion: for each 0·02 per cent or fraction thereof in excess of 0·25 per cent phosphorus there shall be a deduction of 2 cents per unit of manganese per ton.

	Prices per unit.	
	Iron.	Manganese.
Metallic manganese-ore containing above—	*Cents.*	*Cents.*
49 per cent.	6	30
46 to 49 per cent.	6	29
43 to 46 per cent.	6	28
40 to 43 per cent.	6	27

[1] 'Mineral Resources of the United States' for 1905, published in 1906.

'NOTE.—Ore containing less than 40 per cent manganese or more than 12 per cent silica or 0·27 per cent phosphorus, subject to acceptance or refusal, buyer's option.

'Settlements are based on analysis of sample dried at 212°F., the percentage of moisture in the sample as taken being deducted from the weight.

'Prices subject to change without notice, unless otherwise specially agreed upon.'

Use of the Vizagapatam ores.

The Indian ores containing in excess of 0·27 per cent. of phosphorus are those of Vizagapatam. These are sent to the Continent, where they are said to be used in smelting the minette ores of Luxemburg and Lorraine, being mixed with the iron ores in the blast-furnace burden in order to produce a pig low in sulphur, but high in manganese and phosphorus, for use in the basic Bessemer process of steel manufacture.

Special prices.

As there are in many parts of the world manganese-ores that do not come within the limits of the schedules for the purchase of manganese-ores, it is often necessary to arrange special prices to suit special cases.

Thus, according to the 'Mineral Industry' for 1905:

'Russian ore of ordinary grades, during the five years 1898—1902, sold at an average price of $11·54 per ton. More recently, however, prices, particularly of high-grade ore, have advanced strongly. The price is based on 50 per cent. manganese, with phosphorus not to exceed 0·17 per cent., nor silica 9 per cent. Samples are dried at 100°C., and humidity is deducted. Such ore sells at European ports for 16 to 28c. per unit of manganese: from 5 to 10c. per ton is deducted for each per cent. of silica.

'On Turkish ore, the base is 45 per cent. manganese, with limits of 0·03 for phosphorus and 11 per cent. for silica.

'Japanese brown ore sells at Hamburg at from $12 per ton for 65 per cent. MnO_2 ore (41 per cent. Mn.) to $27·60 for 87 per cent. MnO_2 ore (55 per cent. Mn.)

'For German ore, the price is calculated on a basis of 50 per cent. MnO_2 at $4·80 per ton, with an increase of 24c. for each unit of dioxide above 50.

'French ore, calcined, with 35 to 40 per cent. manganese, in 1904 brought 30c. per unit.'

Valuation of ores for chemical purposes.

The prices noticed in the preceding pages are those obtaining for manganese-ores destined for use in the iron and steel industry. For chemical purposes, however, it is not the percentage of manganese that is of importance, but the oxygen in the form of peroxide of manganese, MnO_2, this oxygen being known as *available oxygen*, because it can be liberated from the ore on treating it with acid. The prices obtained for ores fitted for chemical purposes are often much

higher than those given above for ores used for the iron and steel industry. This question I have discussed in the chapter on the uses of manganese, where (page 599) the prices will be found, as well as the points that have to be taken into account in valuing an ore for chemical purposes.

Nomenclature of manganese-ores and manganiferous iron-ores.

It will be interesting to discuss the question of the nomenclature of manganese-ores for commercial purposes, dealing only with those used in the metallurgical industry; for these form by far the larger proportion of the whole. It is customary to divide the ores containing manganese into *manganese-ores* proper, and *manganiferous iron-ores*. There is every gradation in composition between iron-ores practically free from manganese, through iron-ores containing larger and larger quantities of manganese, to manganese-ores containing large quantities of iron, and from these, through manganese-ores containing smaller and smaller quantities of iron, to manganese-ores practically free from this constituent. All these grades of ore are of use in the iron and steel industry. It is customary to divide them into iron-ores, manganiferous iron-ores, and manganese-ores. The difficulty is to decide what is the minimum percentage of manganese in an iron-ore that shall necessitate the prefixing of the adjective 'manganiferous', and what is the minimum percentage of manganese that shall necessitate calling an ore 'manganese-ore' instead of 'manganiferous iron-ore'. I understand that the least percentage of manganese in an iron-ore that is usually paid for is 8%. And it hardly seems necessary to call an iron-ore 'manganiferous iron-ore' if it contain a smaller percentage of manganese than 5. It was formerly the custom in the United States to call an ore a manganiferous iron-ore if it contained less than 44% manganese (equivalent to 70% MnO_2). Later, ores with as little as 40% Mn have been termed manganese-ores, and those below this limit manganiferous iron-ores. According to this method one often sees an ore referred to as a manganiferous iron-ore that contains more manganese than iron. This seems to me to be irrational[1], and easily to be avoided by creating a class of *ferruginous manganese-ores*. Suppose the total of manganese *plus* iron in the ores of

Ferruginous manganese-ores.

1 The commercial nomenclature arises from the buyers and sellers calling *manganese-ore* all ore from which rich ferro-manganese alloys can be made, and *manganiferous iron-ore* such ores as are suitable for making low grade ferro-manganese, and spiegeleisen.

a given area to be usually somewhere about 60%. Then the following classification would seem to be a rational one :—

	Mn. per cent.	Fe per cent.
Manganese-ores	45–60	0–15
Ferruginous manganese-ores	30–45	15–30
Manganiferous iron-ores	15–30	30–45
Iron-ores	0–15	45–60

Although the sum of the Mn and Fe in the ores of the Central Provinces is usually nearly 60%, yet there are many cases where the sum of these two constituents is considerably less than this amount. A reference to the table on page 512 will show that the sum of these two constituents in the average ore of different areas in India varies from 46·77 (Singhbhum) to 59·80% (Chhindwára). For ores in which the sum amounts to 52% the nomenclature would be as follows :—

	Mn. per cent.	Fe per cent.
Manganese-ores	39–52	0–13
Ferruginous manganese-ores	26–39	13–26
Manganiferous iron-ores	13–26	26–39
Iron-ores	0–13	39–52

Similar sets of figures could be drawn up for any other value of Mn + Fe, by dividing the Mn and Fe percentages into four equal sections. In the tables of analyses of Indian ores given on pages 501 to 513, I have used this principle in classifying the ores, extending, however, the class of manganiferous iron-ores in accordance with the next paragraph.

For commercial purposes, however, one table for all ores would probably be considered desirable. Hence to allow for the facts, (i) that ores

from different sources show a different average value for Mn+Fe, and (2) that iron-ores containing 5 to 15% Mn, which in the foregoing classifications would be designated iron-ores without any qualifying adjective, would yet command a special price on account of the manganese present, and (3) that ores containing more than 10 % iron or possibly more than 8 %) had better be classed as ferruginous manganese-ores, and (4) that some iron-ores give nearly 70 % Fe. on bulk analyses, I propose the following, 'or something very close to it, as a more rational classification than the one at present in use :—

	Mn. per cent.	Fe per cent.
Manganese-ores	40–63	0–10
Ferruginous manganese-ores	25–50	10–30
Manganiferous iron-ores	5–30	30–65
Iron-ores	0–5	45–70

This table is applicable to all ores with over 50 % of Mn+Fe. It will also be found to apply to many with less than 50 % of Mn+Fe. For ores with Mn+Fe less than 50 it would be easy to construct another table.

The classification of ores in this way is roughly conformable with the product to be manufactured from each The four divisions correspond roughly to higher grade ferro-manganese, low-grade ferro-manganese, spiegel-eisen, and pig-iron.

Analyses of Indian Manganese-ores.

Tables of analyses.

In the following tables I group together for convenient reference the analyses that have been made of bulk samples collected by myself either from the outcrops, or from the ore-stacks, of the different Indian manganese-ore deposits. In cases where I have not taken samples I give analyses kindly supplied to me by the companies or individuals working the deposits. These analyses are also scattered throughout the text of the descriptive portion of this Memoir under the headings of the respective deposits. A

few of the analyses represent hand-specimens; whenever this is the case it is so stated.

TABLE 55.

Analyses of manganese-ores and manganiferous iron-ores from Singhbhum, Bengal.[1]

Locality.	Matkam-hatu.	Matkam-hatu.	Tekra-sai.	Gitilpi.	Gitilpi.	Bistam-pur.	Tekra-sai.[2]	Tekra-sai.[2]	Tekra-sai.[2]
Nature of the ore.	Psilo-melane and limon-ite.	Manga-niferous limon-ite and hema-tite.	Psilo-melane.	Manga-niferous limon-ite.	Psilo-melane.	Psilo-melane with pyro-lusite.	Psilo-melane.	Psilo-melane.	Psilo-melane.
Number of sample.	A. 36	A. 37	A. 33	A. 34	A. 35	A. 38	A. 380	A. 381	J. 917
Manganese .	20·66	4·23	48·08	10·62	48·01	46·89	50·66	55·61	57·14
Iron . .	25·60	41·30	1·22	38·00	6·10	1·37	0·15	0·05	0·35
Silica .	16·58	18·10	8·30	14·70	1·45	3·15	0·05	0·05	0·10
Phosphorus .	0·701	1·177	0·416	0·353	0·347	0·269	0·322	0·295	0·304
Moisture .	1·00	1·40	0·55	1·10	0·55	0·80	0·45	0·45	0·35

TABLE 56.

Analyses of manganese-ores from the Panch Mahâls, Bombay.[1]

Locality.	Sivarájpur.				
Number of sample.	A. 44	A. 45	A. 4	A. 47	A. 607
Manganese	38·77	48·41	49·35	30·20	51·40
Iron	3·40	3·60	6·25	3·05	4·20
Silica	25·80	7·20	2·80	40·65	6·90
Phosphorus	0·223	0·158	0·253	0·174	0·160
Moisture	0·30	0·35	0·35	0·40	0·60

[1] By Messrs. J. & H. S. Pattinson, of Newcastle-on-Tyne.

[2] Analyses of hand-specimens, not samples.

TABLE 57.

Analyses of manganese-ores from the Sátára District, Bombay.[1]

Locality.	Lingmála.	Bhekowli.	Chikhli.	Yeruli.
Number of sample.	A. 48	A. 50	A. 51	A. 52.
Manganese	37·58	41·89	45·62	38·08
Iron	9·25	4·40	5·00	9·10
Silica	3·45	2·90	3·90	4·75
Phosphorus	0·036	0·073	0·060	0·098
Moisture	2·50	2·00	1·70	1·75

TABLE 58.

Analyses of manganese-ores from Jhábua State, Central India.[1]

Locality.	Kájlidongri.			Rambháp ur.		Kájlidongri.[2]		
Number of Sample.	A. 39	A. 40	A. 41	A. 42	A. 43	A. 467	A. 505	A. 520
Manganese . . .	47·77	48·49	48·25	44·29	45·92	50·02	53·53	57·85
Iron . . .	8·60	10·40	9·45	7·90	5·86	6·75	3·30	3·00
Silica . . .	6·60	8·40	8·60	5·85	11·25	5·60	4·25	8·70
Phosphorus . .	0·165	0·24	0·27	0·18	0·17	0·05	0·06	0·07
Moisture . . .	0·20	0·20	0·45	0·75	0·55	0·20	0·20	0·40

[1] By Messrs. J. & H. S. Pattinson of Newcastle-on-Tyne.
[2] Analyses of hand-specimens, not samples.

TABLE 59.

Analyses of manganese-ores from the Bálághát district, Central Provinces.[1]

Locality.	Jámrapáni.	Thirori.	Thirori.	Thirori.	Thirori.	Ponia.	Jám.	Razrama.	Katangjheri I.	Katangjheri II.	Bálághát.	Ukua (Guina portion).	Ukua (Ukua and Samnapur portion).	Bálághát.[2]
Number of sample.	53	48	49	50	52	51	56	57	58	59	60	61	62	1246
Manganese	51·69	52·06	50·42	52·16	52·92	54·51	49·15	52·78	53·96	49·08	52·63	51·23	51·85	54·42
Iron	8·80	7·53	7·66	6·99	6·82	8·85	9·10	7·83	5·97	6·63	5·28	7·29	7·48	3·10
Silica	3·12	2·74	5·44	2·50	5·08	4·30	2·14	5·35	6·02	1·62	2·62	2·17	5·55	1·40
Phosphorus	0·100	0·109	0·105	0·144	0·122	0·078	0·166	0·092	0·0 9	0·112	0·052	0·236	0·126	0·020
Moisture	0·38	0·30	0·21	0·70	0·32	0·40	0·34	0·22	0·23	0·85	0·12	0·40	0·30	0·15

TABLE 60.

Analyses of manganese-ores from the Bhandárá district. Central Provinces.[1]

Locality.	Kosumbah.	Kosumbah.	Sitapathdr.	Suki.	Miragpur.	Chikhla II.	Kurmura.	Kurmura.	Kurmura.	Chikhla I.	Sitasóngi.	Sitasóngi.	Pachára.
Number of sample.	44	45	47	46	54	55	38	39	40	41	42	43	37
Manganese	49·90	51·33	51·70	54·07	49·81	53·76	49·00	52·81	51·52	53·78	52·83	53·76	52·09
Iron	9·95	10·25	8·14	4·305	8·74	5·12	5·60	6·01	6·81	6·60	4·26	5·41	3·86
Silica	5·22	2·69	6·19	2·30	5·89	6·47	6·18	2·08	4·00	3·60	6·03	6·50	2·61
Phosphorus	0·144	0·135	0·096	0·126	0·087	0·057	0·157	0·340	0·161	0·166	0·096	0·070	0·166
Moisture	0·09	0·70	0·17	1·00	0·34	0·64	0·23	0·41	0·40	0·20	0·24	0·11	1·15

[1] By the Imperial Institute, London.
[2] Hand-specimen, not a sample. By Messrs. J. & H. S. Pattinson.

TABLE 61.

Analyses of manganese-ores from the Chhindwára district, Central Provinces.[1]

	Kachi Dháná.	Lakhanwára.	Gaimukh.	Sitapár.	Sitapár.	Devi.	Ghoti.	Wagora.	Gowári Warhona.	Kachi Dháná.[2]	Gowári Warhona.[3]
Number of sample.	9	11	12	10	10A	13	14	8	7	797	752
Manganese . . .	54·73	50·41	54·98	54·97	54·57	48·95	49·55	29·08	53·59	54·60	55·94
Iron	5·00	11·77	6·19	6·89	7·03	7·03	7·71	6·88	5·00	4·69	8·44
Silica	6·99	4·86	10·63	6·95	7·90	4·98	8·74	36·68	6·21	8·75	1·71
Phosphorus . .	0·07	0·20	0·04	0·06	0·12	0·28	0·28	0·15	0·07	0·01	0·03
Moisture . . .	0·17	0·39	0·32	0·00	0·04	1·27	0·52	0·86	0·31	0·09	0·07

[1] By the Imperial Institute, London.
[2] Hand-specimen, not a sample. By Messrs. J. & H. S. Pattinson.
[3] Hand-specimen, not a sample. By the Imperial Institute.

TABLE 62.

Analyses of samples of manganese-ore from the Nágpur district, Central Provinces.[1]

Localit .	Kodegáon.	Gumgáon.	Rámdongri.	Rámdongri.	Rámdongri.	Rámdongri.	Kándri.	Kándri.	Mansar.	Mansar.	Mansar Extension.	Borda.	Sátak.	Beldongri.	Beldongri.
Number of sample	1	2	3	4	5	6	*a*	*a*	*a*	*a*	19	20	24	25	26
Manganese .	52·54	53·05	53·34	54·07	53·17	51·31	56·62	54·96	54·93	54·00	52·27	55·15	52·37	53·11	54·28
Iron . .	7·60	5·565	8·27	5·92	6·01	7·00	3·72	4·79	4·82	..	5·07	3·77	4·38	5·635	5·44
Silica . .	4·08	4·47	5·47	6·08	6·53	7·64	8·77	8·15	6·94	9·79	16·77	8·93	5·69	5·08	4·80
Phosphorus .	0·10	0·12	0·08	0·10	0·06	0·15	0·09	0·07	0·05	0·09	0·17	0·65	0·065	0·06	0·06
Moisture . .	0·28	0·33	0·37	0·38	0·36	0·63	..	..	..	..	0·60	0·11	0·16	1·17	0·88

Locality.	Nandapuri.	Lohdongri.	Kácharwáhi.	Waregáon.	Mándri.	Mándri.	Mándri.	Mánegáon.	Guguldoho.	Guguldoho.	Páli.	Páli.	Ghogara (Pench R.)	Mándvi Bir B.	Junawáni. A.
Number of sample	27	28	29	30	31	32	33	34	35	36	15	16	18	21	23
Manganese .	51·05	49·73	52·58	50·73	51·26	51·11	47·80	49·15	51·43	46·24	50·78	48·33	42·28	54·71	53·59
Iron . .	6·12	7·20	7·60	7·92	7·55	6·81	6·71	10·26	8·57	16·34	5·425	2·09	4·82	3·30	3·28
Silica . .	5·15	4·41	7·93	5·96	5·78	5·60	8·83	5·31	6·99	2·90	5·45	18·48	10·02	9·00	6·55
Phosphorus .	0·09	0·07	0·08	0·070	0·08	0·09	0·11	0·09	0·15	0·18	0·09	0·06	0·04	0·14	0·05
Moisture . .	0·22	0·30	0·38	0·65	0·69	0·49	1·10	0·35	0·28	0·54	1·32	0·43	0·21	0·34	0·23

[1] By the Imperial Institute, London.
(*a*) Kindly supplied by Mr. W. H. Clark, Manager of the Central Provinces Prospecting Syndicate. They represent large quantities of ore.

TABLE 63.

Analyses of hand-specimens of manganese-ore from the Nágpur district, Central Provinces.

Locality.	Kándri.	Kándri.	Kándri.	Mansar.	Parsoda.	Beldongri.	Beldongri.	Beldongri.	Lohdongri.	Kácharwáhi.	Kácharwáhi.	Gugulduho.	Gugulduho.	Páli.	Junawani.
Nature of specimen.	Braunite and Mn_2MnO_3.	Braunite and hematite ?	Braunite and psilomelane.	Braunite and psilomelane.	Psilomelane, braunite, and hematite ?	Braunite and psilomelane.	Beldongrite.	Vredenburgite.	Braunite and psilomelane.	Braunite and Mn_2MnO_3.	Braunite crystal.	Manganmagnetite (?), psilomelane and wad.	Psilomelane.	Pyrolusite.	Hollandite and braunite.
Number of specimen.	982	994	995	1037	1017	1074	1079	1080	1089	1093	1110	1155	1157	932	1062
Manganese .	57·41	49·60	58·55	57·39	39·43	58·95	40·43	44·62	56·12	58·74	57·86	42·27	57·78	60·79	55·08
Iron . .	2·89	11·98	3·37	3·07	20·56	1·99	5·24	20·19	6·15	3·14	3·85	22·15	1·05	0·04	4·28
Silica . .	9·05	9·26	7·81	5·95	3·09	5·32	19·13	1·77	6·84	8·64	8·60	0·35	0·25	0·33	4·58
Phosphorus .	0·16	0·21	0·065	0·09	0·065	0·035	0·02	0·47	0·035	0·09	0·035	0·03	0·37	0·004	0·17
Moisture .	0·10	0·10	0·15	0·16	0·15	0·20	4·21	0·18	0·07	0·05	0·10	0·55	0·25	0·12	0·36

TABLE 64.

Analyses of manganese-ores, manganiferous iron-ores, and iron-ores, from the Jabalpur district, Central Provinces.[1]

Class of ore.	Manganese-ores.			Manganiferous iron-ores.							Iron-ores (slightly manganiferous).			
Locality.	Dharampura.	Gosalpur.	Bhátádon.	Sakri.	Pahárewa.	Mangeli.	Mansakra.	Dharampura.	Sakri.	Kashi Hill.	Mansakra.	Sakri.	Mangela.	Jauli.
Mineralogical character of the ore.	Psilomelane.	Pyrolusite.	Wad.	Psilomelane and manganiferous chile (Ferruginous manganese-ore).	Pyrolusite.	Pyrolusite.	Pyrolusite and limonite.	Manganiferous hematite.	Manganiferous hematite.	Manganiferous limonite.	Limonite with veins and nests of pyrolusite and psilomelane.	Limonite with veinlets of psilomelane.	Micaceous hematite.	Hematite.
Number of sample	A.18	A.16	67	66	68	A.6	63	A.17	69	A.8	64	65	A.7	A.10
Manganese	45·36	56·80	34·53	22·14	24·65	25·80	24·00	22·34	16·91	6·20	1·29	0·71	1·70	0·16
Iron	10·30	1·60	2·47	19·17	26·64	26·20	31·47	24·70	26·17	47·10	51·12	42·08	48·90	59·90
Silica	1·40	1·85	4·79	23·40	17·30	11·35	4·40	19·65	9·73	5·10	5·21	11·63	20·40	5·80
Phosphorus	0·46	0·155	0·03	0·06	0·135	0·29	0·22	0·155	0·02	0·85	0·32	0·45	0·48	0·04
Moisture	0·90	0·40	0·39	0·34	0·12	0·60	0·44	0·30	0·14	0·65	0·38	0·29	0·35	0·30

[1] Analyses by the Imperial Institute (Nos. 63—69), and Messrs. J. and H. S. Pattinson (Nos. A. 6—A. 18).

TABLE 65.

Analyses of samples of manganese-ores and ferruginous manganese-ores from the Vizagapatam district, Madras.[1]

Locality.	THE KODUR MINES.								RAMABHADRAPURAM.		
	Garividi.	Kodur.	Devâda.	Sandan-andapur-am.	Perapi.	Garbhâm.	Garbhâm.	Kotakarra.	Avagudem.	Sonpuram.	Mâmidi-pilli.	Bankuru-valsa.
Number of sample.	A.28	A.27	A.30	A.29	A.31*	A.21	A.22*	A.20*	A.32*	A.24*	A.25*	A.26
Manganese .	46·93	47·11	47·08	49·05	40·10	46·78	38·67	40·64	39·41	40·54	32·21	46·98
Iron . .	9·80	9·70	7·10	4·80	13·20	9·50	15·70	13·70	13·30	13·60	15·20	9·10
Silica . .	4·70	3·15	1·10	1·90	3·60	4·10	7·30	3·70	4·73	3·40	10·30	4·50
Phosphorus .	0·134	0·191	0·179	0·157	0·207	0·331	0·368	0·134	0·440	0·200	0·482	0·461
Moisture .	0·75	0·65	1·00	0·75	1·10	0·50	0·50	1·85	1·00	0·70	1·35	0·60

TABLE 66.

Analyses of hand-specimens of manganese-ores (some ferruginous) from the Vizagapatam district, Madras.[1]

Locality.	Garividi.	Garividi.	Garividi.	Kodur.	Kodur.	Kodur.	Kodur.	Garbhâm.	Garbhâm.	Avagudem.
Name of Mineral.	Braunite.	Vredenburgite.	Braunite.	Pyrolusite.	Psilomelane with braunite.	Psilomelane with manganmagnetite.	Wad.	Wad.	Psilomelane.	Lead-like psilomelane.
Number of specimen.	A.345	A.346*	A.348	A.197	A.334	A.336	A.338	A.221	A.228	A.372
Manganese . .	51·88	45·62	51·13	59·78	52·58	47·50	41·59	39·95	43·61	49·18
Iron . . .	9·90	21·90	10·10	0·05	4·60	9·20	4·10	5·45	12·10	4·00
Silica . . .	8·25	0·20	8·15	0·50	2·00	4·70	3·40	10·95	3·00	0·45
Phosphorus .	0·031	0·012	0·024	0·417	0·215	0·114	0·114	0·086	0·305	0·346
Moisture . .	0·25	0·20	0·25	0·25	0·30	0·20	4·35	1·55	0·70	2·05

[1] By Messrs. J. and H. S. Pattinson.
* 'Ferruginous manganese-ores', according to the nomenclature proposed on page 500.

TABLE 67.

Average analyses of the manganese-ores[1] *of the Vizagapatam district, Madras, as supplied by the Vizianagram Mining Company.*

Locality.	Garividi.	Kodur.	Sandanandapuram.	Perapi.	Itakerlapilli.	Garbhám.	Avagudem.	Garuja.
Manganese .	43·02	49·69	48·14	41·63	43·00	45·39	42·41	41·45
Iron . .	10·02	7·41	2·35	11·52	8·74	9·99	12·90	11·70
Silica . .	5·03	3·20	3·05	4·30	5·70	4·43	3·85	3·63
Phosphorus .	0·259	0·297	0·262	0·286	..	0·450	0·375	0·298

TABLE 68.

Average analyses of the ferruginous manganese-ores[2] *of the Vizagapatam district, as supplied by the Vizianagram Mining Company.*

Locality.	Perapi.	Garbhám.	Avagudem.	Aitemvalsa.	Bondapilli.	Garuja.	Rámabhadrapuram.
Manganese . .	36·17	35·43	35·75	35·77	38·48	38·51	37·11
Iron . . .	15·69	19·32	16·89	12·87	14·22	13·20	14·22
Silica . .	5·40	6·90	5·95	..	4·93	5·50	5·65
Phosphorus .	0·204	0·423	0·439	0·222	0·332	0·269	0·455

Summary of tables of analyses.

It will be convenient to summarize the figures given in the foregoing tables. In table 69 I have given the range, and in table 70 the mean, of the various constituents of the ores of each area as given in the tables on the preceding pages. The Belgaum, Dhárwár, Sandur, and Mysore, figures I have summarized from analyses kindly supplied by the firms concerned, but not reproduced in detail here.

[1] They include some ferruginous manganese-ores.
[2] Designated manganiferous non-ores by the Vizianagram Mining Company.

TABLE 69.

Range of analyses of manganese-ores and manganiferous iron-ores from the different districts and provinces of India.

PROVINCE.	BENGAL.		BOMBAY.					CENTRAL INDIA.	CENTRAL PROVINCES.		
DISTRICT.	SINGHBHUM.		BELGAUM.[1]		DHÁRWÁR (SANGLI).[2]	PANCH MAHÁLS.	SÁTÁRA.	JHÁBUA.	BÁLÁGHÁT.	BHANDÁRA.	CHHINDWÁRA.
Class of ore.	Manganese-ore.	Manganiferous iron-ore.	Manganese-ore (some ferrug.)	Manganiferous iron-ore.	Ferruginous manganese-ore.	Manganese-ore.	Manganese-ore.	Manganese-ore.	Manganese-ore.	Manganese-ore.	Manganese-ore.
Number of analyses.	3	3	10	2	10	4	4	5	13	13	9
Manganese .	46·89—48·08	4·23—20·66	31·20—60·85	8·34—12·84	19·45—38·48	30·20—49·35	37·58—45·62	44·29—48·49	49·08—54·51	49·00—54·07	48·95—54·97
Iron . .	1·22— 6·10	25·60—41·30	0·10—18·38	47·22—51·88	13·3 —25·3	3·05— 6·25	4·40— 9·25	5·86—10·40	5·28— 9·10	3·86—10·25	5·00—11·77
Silica .	2·45— 8·30	14·70—18·10	0·65— 2·50	1·85— 2·70	7 —31	2·80—40·65	2·90— 4·75	5·85—11·25	1·62— 6·02	2·08— 6·50	4·98—10·63
Phosphorus.	0·27— 0·42	0·35— 1·18	0·01— 0·12	0·02— 0·025		0·16— 0·25	0·04— 0·10	0·165—0·27	0·04— 0·24	0·06— 0·34	0·06— 0·28
Moisture .	0·55— 0·88	1·00— 1·40				0·30— 0·40	1·70— 2·50	0·20— 0·75	0·12— 0·85	0·09— 1·00	0·00— 1·27

[1] From analyses, by Messrs. Pearson of London, supplied by Mr. C. Aubert.
[2] From analyses, by Major Collis Barry, supplied by the Bombay Co., Ld.

TABLE 69—*contd.*

PROVINCE.	CENTRAL PROVINCES—*contd.*				MADRAS.					MYSORE.		
										SHIMOGA.		
DISTRICT.	NÁGPUR.	JABALPUR.			GANJÁM.	SANDUR.[1]	VIZAGAPATAM.			New Mysore Manganese Company.[2]		Shimoga Manganese Company.[3]
Class of ore.	Manganese-ore.	Manganese-ore.	Manganiferous iron-ore.	Iron-ore.	Ferruginous manganese-ore.	Manganese-ore and ferruginous manganese-ore.	Manganese-ore and ferruginous manganese-ore.	Supplied by Vizianagram Mining Company.		Manganese-ore.		Manganese-ore and ferruginous manganese-ore.
								Manganese-ore.	Ferruginous manganese-ore.	Higher grade.	Lower grade. (Ferruginous.)	
Number of analyses.	30	3	7	4	1	6	12	8	7			9
Manganese	42·28—56·52	34·53—56·80	6·20—25·60	0·16—1·70	28·44	39·47—54·39	32·21—49·05	41·45—49·69	35·43—38·51	44—56	30—44	34·51—55·94
Iron	2·09—16·34	1·60—10·30	19·17—47·10	42·08—59·90	19·70	5·38—19·40	4·80—15·70	2·35—12·90	12·87—19·32	2—10	10—20	4·01—17·25
Silica	2·90—18·48	1·40—4·79	4·40—23·40	5·21—20·40	10·25	0·43—1·00	1·10—10·30	3·05—5·70	4·93—6·90	1—3	2—6	0·22—5·75
Phosphorus	0·04—0·65	0·03—0·46	0·02—0·85	0·04—0·48	0·71	0·02—0·03	0·13—0·48	0·23—0·45	0·20—0·45	0·15—0·06	0·01—0·06	0·01—0·14
Moisture	0·11—1·32	0·39—0·90	0·12—0·65	0·29—0·38	2·55	..	0·50—1·85	..	..	about 1	about 1	..

[1] From analyses, supplied by Mr. C. Aubert.
[2] Estimated figures by Mr. C. S. Fawcitt.
[3] From analyses, by various chemists, supplied by Miss A. E. Dawson.

TABLE 70.

Mean of analyses of manganese-ores and manganiferous iron-ores from the various districts and provinces of India.

PROVINCE.	BENGAL.		BOMBAY.					CENTRAL INDIA.	CENTRAL PROVINCES.						
DISTRICT.	SINGHBHUM.		BELGUM.		DHÁRWÁR (SÁNGLI).	PANCH MAHÁLS.	SÁTÁRA.	JHÁBUA.	BÁLÁGHÁT.	BHANDÁRA.	CHHINDWÁRA.	NÁGPUR.	JABALPUR.		
Class of ore.	Manganese-ore.	Manganiferous iron-ore.	Ferruginous manganese-ore.	Manganiferous-iron-ore.	Ferruginous manganese-ore.	Manganese-ore.	Manganese-ore.	Manganese-ore.	Manganese-ore.	Manganese-ore.	Manganese-ore.	Manganese-ore.	Manganese ore.	Manganiferous iron-ore.	Iron ore.
Number of analyses.	3	3	10	2	10	4	4	5	13	13	8	30	3	7	4
Manganese .	47·66	11·84	44·77	10·53	31·62	41·68	40·79	46·94	51·88	51·94	52·72	51·53	45·56	20·26	0·96
Iron .	2·90	34·93	10·33	49·55	16·8	4·07	6·94	8·44	7·40	7·27	7.08	6·24$\frac{29}{30}$	4·79	28·78	50·50
Silica .	4·63	16·46	1·40	2·27	19·1	19·11	3·75	8·14	3·74	4·59	7·16	7·25	2·68	12·99	10·76
Phosphorus.	0·34	0·74	0·035	0·023	..	0·20	0·07	0·20	0·11	0·14	0·14	0·11	0·215	0·25	0·32
Moisture .	0·63	1·17	..	..	..	0·35	1·99	0·43	0·37	0·44	0·38	0·49$\frac{88}{89}$	0·56	0·37	0·33
Manganese + Iron .	50·56	46·77	55·10	60·08	48·42	45·75	47·73	55·38	59·28	59·21	59·80	57·77	50·35	49·04	51·40

TABLE 70—*contd.*

PROVINCE.	MADRAS.					MYSORE.		
						SHIMOGA.		
DISTRICT.	GANJÁM.	SANDUR.	VIZAGAPATAM.			New Mysore Manganese Co.		Shimoga Manganese Co.
				Supplied by Vizianagram Mining Co.		Ferruginous manganese-ore.		
Class of ore.	Ferruginous manganese-ore.	Ferruginous manganese-ore.	Ferruginous manganese-ore.	Manganese-ore.	Ferruginous manganese-ore.	Higher grade.	Lower grade.	Manganese ore.
Number of analyses.	1	6	12	8	7	3	Half the limits.	9
Manganese .	28·44	47·75	42·96	44·34	36·75	46·75	37	49·10
Iron . .	19·70	11·45	11·22	9·08	15·20	10·06	15	7·74
Silica . .	10·25	0·61	4·29	4·15	5·72⅝	1·77	4	2·62
Phosphorus.	0·71	0·030	0·27	0·32	0·335	0·031	0·035	0·085
Moisture .	2·55	..	0·90	..	..	0·95	1	..
Manganese + Iron	48·14	59·20	54·18	53·42	51·95	56·81	52	56·84

Analyses of Indian ores expected by buyers.

For comparison with the figures given in table 69 I give below in table 71 figures, obtained from a reliable source, showing the range in the composition of the ores that buyers expect to obtain when contracting for the purchase of various Indian ores. It will be seen that they agree very well, with one or two exceptions, with my figures given in table 69. The most marked exception is the Panch Maháls. My figures are probably lower than would be obtained in practice, because I took average samples from the outcrop without any selection, such as would naturally take place when the ores came to be worked. Some of these samples are, moreover, probably from parts of the outcrop that it has not been found profitable to work.

TABLE 71.

Analyses of Indian manganese-ores for which buyers stipulate when making contracts.

PROVINCE.	BOMBAY.	CENTRAL INDIA.	CENTRAL PROVINCES.			MADRAS.		MYSORE.
DISTRICT.	PANCH MAHÁLS.	JHÁBUA.	NÁGPUR, BALÁGHÁT AND BHANDÁRA.	NÁGPUR AND BHANDÁRA.	NÁGPUR.	SANDUR.	VIZAGAPATAM.	SHIMOGA.
Shipping firms.	Shivrájpur Syndicate, Ld.	Kiddle, Reeve & Co.	Central Provinces Prospecting Syndicate, Ld.	Central India Mining Co., Ld.	Indian Manganese Co., Ld.	Jambon & Cie.	Vizianagram Mining Co., Ld.	Mysore Manganese Co., Ld., and the Madras Mining Syndicate.
				1st grade. / 2nd grade.				
Manganese	51—52	46—48	52—54	51—52 / 46—48	50—52	44—46	45—47	46—47
Iron	6— 8	4—7	4—6	6—7 / 6—8	5—6	13—16	12—14	9—10
Silica	5— 6	8—9	6—7	7—8 / 9—11	6—8	2—4	3—4	3—4
Phosphorus	0·17— 0·18	0·13—0·16	0·07—0·08	0·09—0·11 / 0·13—0·17	0·11—0·14	0·05—0·06	0·26—0·33	0·04—0·05

Analyses of the Manganese-ores of the World.

Analyses of cargoes of Indian and foreign ores landed at Middlesborough.

In tables 72 and 73 I give the limits and averages, respectively, of figures of analysis of cargoes of manganese-ores and manganiferous iron-ores landed during the years 1897—1906 at Middlesborough. The figures were obtained by Dr. T. H. Holland in 1906 and represent not only Indian manganese-ore, but also the manganese-ores of the Caucasus, Brazil, and Chile, and the manganiferous iron-ores of Greece and Spain (*viâ* Carthagena). From these figures it will be seen that the Indian ores contain less moisture than those of the other countries. Some of the latter contain such large quantities of moisture—Caucasus, 8·67%; Brazil, 11·35%; and Spain, 8·44%—that it is necessary to reduce the analyses to their condition when dried at 100°C. before any fair comparison can be made. This has been done by assuming that the constituents of the ores not given in the 'as received' columns would if determined make the analyses add up exactly to 100. From the figures representing the dried ores it will be seen that the Indian ores stand first as regards manganese contents, with Brazil a close second: as regards silica, Brazil stands first, with India second: as regards phosphorus, however, India stands last but one, the only ores containing more phosphorus being those of Russia: the Indian ores contain much less iron than the manganiferous iron-ores of other countries; but of the true manganese-ores they contain the highest amounts of iron, in spite of the fact that they also contain the highest amounts of manganese. This feature of the Indian ores as regards iron contents may be regarded as a point in their favour, or otherwise, according to the use to which the ores are to be applied. It is true that the high iron contents makes it more difficult to manufacture the very highest grades of ferromanganese from the Indian ores; but on the other hand if the very highest grades are not required then the iron is of considerable value. Both manganese and iron are of use in this case, and the buyer obtains the following totals of Mn + Fe when he buys the ores of the different countries:—

	Mn + Fe %
India	57·17
Brazil	54·09
Russia	50·41
Chile	48·40
Greece	47·99
Spain	44·27

As regards phosphorus, the figures for the Indian ores are rather misleading; for an examination of the analyses from which these figures have been taken shows that the ores consist of two different varieties. The majority of analyses are typical of the ores of the Central Provinces, whilst four of them probably represent ores from the Vizagapatam district. I have accordingly separated them into two groups, of which the limits and averages are given in tables 74 and 75. From these figures it will be seen that the Central Provinces ores average 0·096% and the Vizagapatam ones 0·291% in phosphorus.

TABLE 72.

Limits of analyses of cargoes of manganese-ores and manganiferous iron-ores landed at Middlesborough during the 10 years 1897—1906.

(As received.)

COUNTRY.	INDIA.	RUSSIA (CAUCASUS).	BRAZIL.	CHILE.	GREECE.		SPAIN (*vid* CARTHAGENA.)
Class of ore.	Manganese-ore.	Manganese-ore.	Manganese-ore.	Manganese-ore.	Manganiferous iron-ores.		Manganiferous iron-ores.
					Raw	*Calcined*	
Number of cargoes.	26	77	25	9	54	18	24
Period.	1900–1906	1898–1906	1898–1906	1898–1903	1897–1906	1897–1903	1897–1905.
Manganese . . .	42·13—54·53	40·74—48·98	37·05—48·14	46·44—49·56	8·63—24·44	10·41—23·21	7·32—21·78
Iron	3·85—11·69	0·38— 0·93	2·55— 8·26	0·25— 0·52	18·96—42·75	26·55—43·75	16·38—40·75
Silica	2·63— 9·99	6·91—13·06	0·80— 7·78	6·12— 9·16	2·59—11·52	5·35— 9·70	6·50—17·97
Phosphorus . . .	0·056— 0·331	0·095— 0·17	0·017— 0·130	0·009— 0·018	0·012— 0·044	0·015— 0·038	0·007—0·022
Moisture . . .	0·21— 2·64	5·67—12·35	2·69—19·57	0·54— 2·13	0·56— 8·74	..	4·07—13·78
Alumina, siliceous matter, etc.	3·63—13·18	8·97—15·58	0·92—12·80	11·92—13·47	2·74—12·13	6·20—10·80	6·18—19·52

TABLE 73.

Mean of analyses of cargoes of manganese-ores and manganiferous iron-ores landed at Middlesborough during the 10 years 1897—1906.

COUNTRY.	INDIA.		RUSSIA (CAUCASUS).		BRAZIL.		CHILE.		GREECE.			SPAIN (*vid* CARTHAGENA).	
Class of ore.	Manganese-ore.		Manganese-ore.		Manganese-ore.		Manganese-ore.		Manganiferous iron-ore.			Manganiferous iron-ore.	
									Raw.		*Calcined.*		
Number of cargoes.	26		77		25		9		54		18	24	
Period.	1900—1906		1898—1906		1898—1906		1898—1903		1897—1906		1897—1903	1897—1905	
Method of reporting analysis.	As received.	Dried at 100°C.	As received.	Dried at 100°C.	As received.	Dried at 100°C.	As received.	Dried at 100°C.	As received.	Dried at 100°C.	Dried at 100°C.	As received.	Dried at 100°C.
Manganese	50·49	50·86	45·28	49·58	44·60	50·31	47·51	47·99	16·15	16·96	13·01	19·35	21·13
Iron	6·26	6·31	0·76	0·83	3·35	3·78	0·41	0·41	29·54	31·03	41·32	21·19	23·14
Silica	5·67	5·71	9·29	10·17	1·81	2·04	7·26	7·33	7·37	7·74	7·33	11·18	12·21
Phosphorus	0·126	0·127	0·147	0·161	0·046	0·052	0·015	0·015	0·022	0·023	0·023	0·013	0·014
Moisture	0·72	..	8·67	..	11·35	..	1·01	..	4·79	..	..	8·44	..
Alumina, siliceous matter, etc.	6·75	6·80	11·66	12·77	2·73	3·08	12·52	12·65	8·04	8·44	8·35	12·63	13·79

TABLE 74.

Limits of analyses of Indian ores in Table 72 arranged according to probable source.

Source of ore.	Central Provinces, and possibly Jhábua and Panch Mahals.	Vizagapatam.
Number of cargoes.	22	4
Manganese	47·25 —54·53	42·13 —47·53
Iron	3·85 — 7·98	9·14 —11·69
Silica	3·33 — 9·99	2·63 — 3·66
Phosphorus	0·056— 0·163	0·235— 0·331
Mositure	0·21 — 2·64	0·64 — 0·95

TABLE 75.

Mean of analyses of Indian ores in Table 73 arranged according to probable source.

Source of ore.	Central Provinces, and possibly Jhábua and Panch Mahals.	Vizagapatam.
Number of cargoes.	22	4
Manganese	51·31	45·95
Iron	5·53	10·29
Silica	6·13	3·10
Phosphorus	0·096	0·291
Moisture	0·71	0·76

Analyses of the manganese-ores of the world.

Since the figures given in tables 72 and 73 represent a few only of the manganese-ore producing countries of the world I give in table 76 a further set of figures taken from W. Venator's paper entitled the 'Die Deckung des Bedarfs an Manganerzen', and published in *Stahl und Eisen*, XXVI, pp. 146-148 (1906).

TABLE 76.

Analyses of the manganese-ores of the world.

Source of Ore.	Mn.	Fe.	SiO_2.	P.	H_2O.	Reference or Analyst.
BOSNIA:						
Cevljanovic, dressed ore	46·01	5·30	12·38	0·07	—	Vogel, *Jahrbuch f. d. Eisenhüttenwesen*, 1900, p. 177.
Do. do.	50·42	3·53	11·48	0·07	—	
BRAZIL:						
Miguel Burnier	55·00	—	1·50	0·025	—	Demaret-Freson, p. 6.
Carlos Wigg	44·43	[2·99	0·94	0·03	4·01	J. W. Westmoreland.
Dried ore	53·18	3·58	[1·13	—	—	J. W. Westmoreland; 16·45 % moisture.
Average ore	54·08	0·90	1·05	0·03	—	
English shipments, 1900	51·9—53·4	—	1·0—1·4	0·03[	15·8—18·2	E. Riley and Von E. Göttig.
United States shipments, 1900	51·9—53·5	—	1·1—1·65	0·03[	13·0—16·7	
CHILE:						
Santiago	53·00	—	—	0·05	—	J. D. Weeks, 1894, p. 442.
Coquimbo	52·66	—	—	0·06	—	
Coquimbo	49·79	—	—	0·02	—	
FRANCE:						
Vieille Aure, Hautes-Pyrénées	46·00	—	37·00	—	—	Vogel, *ibid*, p. 176.
Las Cabesses, raw	40·42	1·5—2	6—7	0·04	—	
Do. roasted	50—56	2·00	8—9	0·05	—	
Saint-Giron	45·68	—	5·94	0·43	—	Weeks, *ibid*, p. 445.
Do.	56·48	—	6·48	0·47	—	
Ral el Maden, Algiers	5·89	45·16	12·29	0·09	—	Von E. Göttig.
GREECE:						
Milos	32·16	3·32	19·76	0·04	—	Von E. Göttig.
Average Milos	34·73	3·00	22·92	0·06	—	
Manganiferous iron-ore	17·37	31·10	7·1	0·04	5·9	
HUNGARY:						
Kolozvar	56·51	3·10	3·10	0·06	—	Vogel, *op. cit.*, 1902, p. 226.
INDIA:						
Gosalpur	54·29	1·41	3·27	0·16	2·81	J. D. Weeks, 1895, p. 40.
Average ore	51·43	5·6	9·52	0·09	—	Von E. Göttig.
ITALY:						
Monte Porcile	48·75	—	—	—	—	Vogel, *ibid*, p. 224.
Monte Zenone	42·52	—	19·89	—	—	
Island of St. Pietro, Sardinia	37·00	—	—	—	—	
JAPAN:						
No. 1	51·19	—	7·3	0·06	—	Von E. Göttig.
No. 5	44·09	—	16·1	0·06	—	
Average ore	48·87	—	10·4	0·08	—	
PANAMA:						
Soledad mine	60·60	0·2	4·67	0·01	1·70	J. Birkinbine, 1902, pp. 25 & 28.
Average of 1,500 tons	57·5	—	4·18	—	2·73	
Average of 23,000 tons	53·74	—	8·68	—	—	
Low-grade, siliceous ore	47·00	—	30·00	—	—	
Conception, average of 6 ores	52·18	1·76(?)	4·36	0·06	—	J. Birkinbine, 1902, p. 30.

TABLE 76—*concld.*

Analyses of the manganese-ores of the world—concld.

Source of Ore.	Mn.	Fe.	SiO_2.	P.	H_2O.	Reference or Analyst.
RUSSIA :						
Caucasus, range of 5 analyses	45·5—58·2	0·4—1·35	0·9—7·4	0·13—0·48	0·61—5·78	Von E. Göttig and *Stahl u. Eisen*, 1891, p. 521.
Do. average do.	53·98	0·79($\frac{3}{5}$)	4·62	0·34	2·34($\frac{4}{5}$)	
Poti (Caucasus), average ore	51·01	1·05	9·86	0·17	—	Von E. Göttig.
Nikopol (Ekaterinoslav)	29·5	—	—	0·24	—	
Do. do.	34·6	—	27·00	0·28	—	Von E. Göttig.
Ekaterinenburg (Perm)	53·7	0·86	8·10	Tr.		*Stahl u. Eisen*,
Do. do.	51·2	1·33	9·33	0·36	—	1891, p. 521.
SPAIN :						
Huelva Carbonate ore 4	28·26	6·58	4·95	—	—	
Do. do. 6	41·15	0·77	14·10	—	—	
Santo Domingo 6	38·87	1·37	22·50	—	—	Vogel, *ibid.*, p. 227.
Manganese Carbonate, average from a cargo	38·33	2·31	10·85	0·10	1·54	
Roasted ore	49·6	—	—	—	—	Loss on roasting 20—30 %.
Huelva	43·70	2·51	17·10	0·22	2·19	
Do.	49·15	—	13·0	0·10	—	
Cartagena, manganiferous iron-ore	6·33	42·7	9·53	0·035	9·30	Von E. Göttig.
Las Rozas, do.	7·40	48·45	4·10	0·02	5·72	
UNITED STATES :						
Arkansas, Batesville, range of 5 analyses	50·4—56·9	—3·66	0·7—2·1	0·10—0·29	—2·28	
Do. do. average of 5 analyses	54·90	3·66($\frac{1}{5}$)	1·36($\frac{4}{5}$)	0·18	2·28($\frac{1}{5}$)	J. D. Weeks. 1895, p. 403, *et seq.*
Do. do. Keystone mine	57·30	1·75	2·31	0·12	—	
Do. Martin mine	60·50	1·61	1·0	0·17	10·45	
California, Corral Hollow	47·58	2·28	1·98	—	—	
Do. Red Rock	27·95	3·72	35·32	0·61	—	
Georgia, Cartersville	60·61	1·45	—	0·05	—	J. Birkinbine,
Do. do.	2·30	52·02	—	0·24	—	1902, p. 15,
Do. do. average of 7	41·47	15·41	—	0·14	—	SiO_2 rarely over 10 % : 2–5 % on average.
Do. Cave Spring, pure ore	53·44	1·98	7·79	0·06	1·56	J. Birkinbine, 1902, p. 16.
Do. Dobbins mine	52·72	4·49	4·30	0·19	—	
Do. do.	48·83	5·40	5·05	—	—	
Do. Dade mine	30·32	23·9	6·37	0·1	—	
Do. do.	43·45	4·26	16·45	0·10	—	
Do. do.	42·93	8·53	12·30	0·11	—	
Indian Territory Lehigh, average of 4	38·90	7·06	1·45	0·06	4·37	J. D. Weeks, 1895, p. 403, *et seq.*
Lake Superior, high	12·02	47·93	—	0·05	—	
Do. low	4·89	56·35	—	0·05	—	
Virginia, Crimora mine	57·29	0·37	—	0·075	—	
Do. do. average ore	49·08	2·83	10·21	0·10	—	
Do. Kendall & Flick's mine	48·25	2·70	10·50	—	4·00	

The Rarer Constituents of Indian Manganese-ores.

From the preceding tables of analyses a good idea can be obtained of the proportions in which the constituents that are taken into account

in the valuation of manganese-ores are present in the Indian ores. I now propose to notice in turn the various constituents found in the Indian ores that are not taken into account in the commercial valuation of ores. Except where I state otherwise I shall confine myself to the analyses made by the Imperial Institute and Messrs. J. and H. S. Pattinson of samples collected and specimens selected by myself. I have 20 complete analyses and 62 partial analyses by the Imperial Institute, and 25 complete and 34 partial analyses by J. and H. S. Pattinson, from which to draw conclusions. Though all the partial analyses were of great use in the compilation of the preceding tables they mostly do not show any of the constituents to be considered here. Hence, except in the case of baryta and arsenic I have to rely almost entirely on the complete analyses.

The analyses by the Imperial Institute represent the Central Provinces only; those by J. and H. S. Pattinson represent specimens and samples from Vizagapatam, Jhábua, Singhbhum, Panch Máhals, Sátára, Ganjám, and a few from the Central Provinces a'so.

Alumina in manganese-ores.

Alumina is invariably present in the Indian manganese-ores, though usually to a small extent only. In 45 complete analyses the amount of this constituent ranges between 0·03% (Lohdongri) and 6·84% (Kodur), the average of the whole number being 1·33%. The form in which the alumina is present is a matter of speculation. In the case of psilomelane and hollandite I have found that it can usually be calculated into the formula of the mineral as $Al_4(MnO_5)_3$. It is doubtless often present as an impurity mechanically included in the mineral, however. There is one variety of ore found in Mysore that seems, as far as can be judged from a single analysis by Mr. C. S. Fawcitt, to be particularly aluminous. This is a dull oolitic to pisolitic ore. The specimen analysed came from Kumsi and yielded 13·04 per cent. Al_2O_3.

Baryta in manganese-ores.

Baryta is an almost invariable constituent of manganese-ores. For this constituent I can refer not only to the 45 complete analyses, but also to a large number of the partial analyses carried out by J. and H. S. Pattinson. In 78 analyses the amount of baryta ranges from 0·00% in samples and specimens of mixed braunite and psilomelane, with braunite usually predominant, from Kodegáon, Kachi Dhána, Kándri, and Kácharwáhi, to 13·76 per cent. in a sample of psilomelane with pyrolusite from Bislampur, and 15·08% in a specimen of psilomelane from

Tekrasai, both localities being in Singhbhum. A specimen of hollandite from Kájlidongri analysed by Mr. Winch showed 17·59% BaO. The baryta seems to be present in all or nearly all of these ores in the form of barium manganate, Ba_2MnO_5, in the psilomelane or hollandite. It may also replace manganese in braunite as the molecule $BaMnO_3$. The average amount in the 78 samples and specimens noticed above is 1·88%.

Lime in manganese-ores.

Lime is almost invariably present in Indian manganese-ores. The 45 complete analyses show a maximum of 5·60% in a sample of mixed psilomelane and braunite from Lohdongri, and a minimum of 0·00% in a picked specimen of pyrolusite from Páli. The average of the 45 is 1·07%. In many cases the lime is probably present as a manganate, Ca_2MnO_5, as a part of the psilomelane or hollandite; but in some cases it probably replaces a portion of the manganese in braunite, *e.g.*, in the specimen of this mineral from Sitapár analysed by Mr. Blyth, and found to contain 4·28% CaO.

Magnesia in manganese-ores.

Magnesia is another of the almost invariable constituents of Indian manganese-ores, only one analysis out of 45 showing it absent. This is a specimen of mixed hollandite and braunite from Junawáni. The maximum amongst these 45 analyses is 3·15% in a specimen from Kachi Dhána consisting almost entirely of braunite. The average amount in the 45 analyses is 0·53% MgO. The magnesia probably plays a similar part in manganese-ores to the lime.

Potash in manganese-ores.

Alkalies sometimes form quite an important part of the Indian manganese-ores, potash being much more important than soda. In 25 analyses by J. and H. S. Pattinson the lowest amount of K_2O is 0·05% in specimens from Guguldoho and Kájlidongri. In 19 cases the percentage of K_2O is over 1, the highest amounts being 3·75% in psilomelane containing braunite from Kodur, 3·31% in hollandite with braunite from Bálághát, 3·25% in lead-like psilomelane from Avagudem, 3·10% in psilomelane from Guguldoho, and 2·63% in psilomelane from Tekrasai. The average amount of K_2O in these 25 analyses is 1·17%. In 21 analyses by the Imperial Institute the amount of K_2O ranges from a trace in four cases—namely, braunite with a little psilomelane from Kachi Dhána, pyrolusite from Páli, vredenburgite from Beldongri, and braunite containing a little psilomelane from Kácharwáhi—to 0·82% in a sample

of mixed psilomelane and braunite from Kodegáon, and 0·50% in a specimen of braunite with psilomelane from Kándri. The average of these 21 is 0·175% K_2O. The average of the whole 46 analyses is 0·71% K_2O. The results obtained by the two sets of analysts seem at first sight to be very discrepant. But it must be remembered that the specimens analysed by the Imperal Institute did not include any specimens of psilomelane unmixed with braunite; whilst amongst the specimens analysed by J. and H. S. Pattinson there were several pieces of pure psilomelane, which is the manganese-ore that contains the largest quantities of alkalies. The potash and soda in this mineral probably occur as K_4MnO_5 and Na_4MnO_5, respectively.

Soda in manganese-ores.

In the case of the soda, which is present in much smaller amount than the potash, the two sets of analyses agree very well. 21 analyses by the Imperial Institute show soda present in every case, the smallest amount being 0·13%, and the largest 0·50%, this latter being found in a specimen of braunite mixed with a certain proportion of psilomelane, from Kándri. The 25 analyses by J. and H. S. Pattinson show from as little as 0·02% Na_2O in a specimen of the lead-like psilomelane of Ávagudem, to 0·57% in the hollandite of Bálághát. The average amount in the total of 46 analyses is 0·24%, which is one-third of the average amount of K_2O.

Arsenic in manganese-ores.

An unexpected constituent of the Indian manganese-ores is arsenic. The finding of three different species of arsenates associated with the Indian manganese-ore deposits is noticed on page 218 in the section of mineralogy. It was the detection of the Sitapár arsenate that led to the testing of the Indian ores generally for this constituent. A sample of the Sitapár ore was cleaned into two samples, one free from visible arsenate—which is practically white and hence easily separated—and the other containing all the visible arsenate. The amounts of arsenic oxide, As_2O_5, were found to be 0·003% and 0·095% in the two cases. Fifty-nine samples and specimens of Indian manganese-ores were tested for this constituent. Of these, all tested by the Imperial Institute have been found to contain arsenic, whilst of those tested by Messrs. J. and H. S. Pattinson, 13 have been found to be free from arsenic, and 24 to contain it. The maximum was 0·305% As_2O_5 found in a sample of mixed psilomelane, braunite, and pyrolusite, from Kájlidongri, one of the arsenate localities. Other results of 0·050 or over are: 0·214%, 0·055%, and 0·050%, in other samples from Kájlidongri, 0·066% in a sample of mixed psilomelane,

braunite, and soft oxide, from Mándri: and 0·055% in a sample of psilomelane containing some pyrolusite from Sivarájpur. The average of the 59 determinations is 0·023%. This is fortunately too small an amount to affect the commercial value of the ores. Manganese-ores could probably stand the presence of a considerably larger amount of arsenic than the above without the market value being affected; for such amounts of arsenic would probably be volatilized off in the blast furnace.

Sulphur in manganese-ores.

Every one of 25 analyses by J. and H. S. Pattinson shows a small amount of sulphur. There is remarkable uniformity between the amounts present, the largest being 0·060%, in a sample from Kájlidongri, and the smallest 0·014% in a specimen from Garbhám. The average of the whole 25 is 0·029%. The sulphur may be suspected to be present in the form of minute quantities of barytes, especially as the maximum figure, 0·060% applies to Kájlidongri, in the ores of which I have recognized barytes. Such small amounts of sulphur do no harm. Indeed manganese-ores could probably stand the presence of a considerable quantity of sulphur, without their commercial value being reduced, except in so far as the sulphur took the place of manganese-ore; for manganese acts as a remover of sulphur in the furnace.

Cobalt and nickel in manganese-ores.

There seems to be considerable difference between the results of tests made by different chemists on Indian manganese-ores for the presence of cobalt and nickel. In many cases the chemists attached to the mining companies have been unable to prove the presence of these constituents; whilst in other cases they have detected them. In some analyses that I once made of some Indian ores I found 0·48% of CoO + NiO in a picked specimen of mixed psilomelane-braunite ore from Kodegáon; 0·17 of CoO and 0·38 of NiO in a specimen of wad from Sontulai in the Hoshangábád district of the Central Provinces; and 0·27 of CoO and 0·56 of NiO in a specimen of conglomerate cemented by psilomelane from Pola Khal in the Dhar Forest, Central India. Dr. T. L. Walker found 0·82% of CoO in a specimen of wad from Olatura in the Kalahandi State. In the samples sent to the Imperial Institute the oxides of cobalt, nickel, and copper, were all determined together. The amounts of these constituents in 19 analyses vary from *nil* to 0·08, the average being 0·022%. These analyses all represented specimens and samples from the Nágpur-Bálághát

area of the Central Provinces. In 25 analyses by Messrs. J. and H. S. Pattinson, cobalt is absent from 3 analyses of Kájlidongri samples, and from one of a sample from Mándri. It is shewn as traces only in two analyses of specimens from Kájlidongri. In the remaining analyses it is given as present, the highest amounts being 0·35%, 0·25%, and 0·20%, in three specimens of psilomelane from Tekrasai, and 0·20% in a specimen of braunite crystals from Kácharwáhi. The average of the whole 25 is 0·090%, and of the 19 analyses in which it is estimated, 0·120%. Nickel oxide is returned as absent in 18 out of these 25 analyses, and present in the remainder. The highest amounts are 0·20% and 0·15% in specimens of psilomelane from Tekrasai. The average for the whole 25 analyses is 0·027% and for the 7 in which it is present is 0·095%.

Copper in manganese-ores.

Copper is sometimes found in the Indian manganese-ores, though, as in the case of cobalt and nickel, always in small quantities. The largest amount found was in the sample of wad from Sontulai already mentioned, the amount being 0·47. In the samples and specimens analysed at the Imperial Institute, the copper was returned with the nickel and cobalt, for which see the preceding paragraph. In the 25 analyses by J. and H. S. Pattinson copper was found to be present in every case, although in three cases, Guguldoho, Bálághát, and Mándri, all in the Central Provinces, the amount returned was only a trace. The highest amount of CuO is 0·15% found in a sample from Kájlidongri. 0·034% is the average amount in the 25 analyses. It is interesting to note that a specimen of gondite from Wagora showed 0·02%; a specimen of opalized kodurite from Kotakarra 0·02%; and one of opalized kodurite from Boiráni in Ganjám, a trace of CuO. Gondite and kodurite are of course the rocks from which at least a portion of the manganese-ores of the Central Provinces and Vizagapatam, respectively, have been derived. It is also of interest to notice that the analyses of these rocks do not show the presence of oxides of cobalt and nickel.

Lead in manganese-ores.

Out of 4 samples and 21 specimens in which lead was looked for by J. and H. S. Pattinson, this constituent was found in three samples only, all from Kájlidongri. The amounts were 0·01, 0·02, and 0·02%. An analysis made by James E. Furguson of London, of a sample taken by Mr. J. H. Goodchild to represent the whole of the Mándvi Bir-Junawáni ore-band showed 0·013% PbO.

Zinc in manganese-ores.

In the 25 analyses of specimens and samples by J. and H. S. Pattinson zinc oxide is returned as absent in 9 cases, as a trace in one, and is determined in the remaining cases. The maximum amount of ZnO is 0·55%, found in a specimen of psilomelane from Tekrasai. Amounts of 0·40% and 0·30% ZnO were found in two other specimens of the same mineral from the same locality. The average amount in the whole 25 analyses is 0·102% ZnO. The analysis of the Junawáni sample taken by Mr. Goodchild, noticed in the preceding paragraph, shows 0·070% ZnO. An analysis by Messrs. Pattinson and Stead of a 300-ton cargo of Kodegáon ore shows a trace of this constituent.

It is noticeable that all the rare metallic constituents, cobalt, nickel, copper, lead, and zinc, found in the Indian manganese-ores, tend to occur in greatest amount in specimens of wad and psilomelane. The most noticeable examples are the wad-like psilomelanes of Sontulai and Tekrasai. It is probable that these constituents tend to take the form of manganates of the general formula R_2MnO_5 in the ores in which they are found, though they might also occur in braunite in molecules of the general formula $RMnO_3$.

Titanium in manganese-ores.

In the 25 analyses by J. and H. S. Pattinson titanic oxide is returned as absent in four cases, as a trace in one, and is determined in the remaining analyses. The maximum amounts are 0·14% in a specimen of vredenburgite from Garividi, 0·14% and 0·12% in two samples of mixed psilomelane-braunite ores from Kájlidongri, and 0·13% in a specimen of speckled ore (psilomelane, braunite, and soft oxides) from Guguldoho. The average in the whole 25 analyses is 0·058% TiO_2.

Combined water in manganese-ores.

The amount of combined water in Indian manganese-ores varies greatly with the nature of the ore. It is never *nil*. In 45 analyses the highest amounts are 7·30% in wad from Garbhám; 6·16% in beldongrite, a variety of psilomelane from Beldongri; 5·50% in wad from Kodur; and 4·40% in material intermediate in physical appearance between wad and psilomelane, from Garbhám. The average amount in the 45 analyses is 2·01%. It may be stated as a rough rule that the larger the amount of psilomelane in an ore the larger is likely to be the amount of combined water; and the larger the amount of braunite the smaller the amount of combined water; whilst wad contains an even

larger proportion of combined water than psilomelane. In the psilomelane the water is probably present as H_4MnO_5.

Carbon dioxide in manganese-ores.

Manganese-ores, if free from rhodochrosite, should not contain any carbon dioxide. In 28 analyses by the Imperial Institute, however, CO_2 is returned as present in every case but one. The highest amounts are 3·49% in a sample from Ghogara in the Pench River; 1·14% in a sample of nodule ore from Páli; and 0·41% in a sample of ore, largely braunite, from Gaimukh. In the first two cases the presence of the carbon dioxide is to be ascribed to calcite; for the ores were obtained from crystalline limestones; and in the third case rhodochrosite was seen to be present in the ore. In all the other examples the highest amount of CO_2 is 0·35%; and the average of these 25, excluding the foregoing 3, is 0·106%; and as there seems to be no way of accounting for the presence of this CO_2 by means of visible calcite or rhodochrosite, it seems necessary to suppose that there may be microscopic amounts of one or other of these minerals disseminated through the ores, the calcite having perhaps been introduced by percolating waters. Another hypothesis is that these small amounts are the result of experimental errors connected with the determination of such small amounts of a gas. In 25 analyses by Messrs. J. and H. S. Pattinson this constituent is returned as absent in every case.

CHAPTER XXV.

ECONOMICS & MINING—*continued.*

Value of the Indian Manganese-ore Production.

Official statistics—The *f.o.b.* or export value, the true value to India—Tables of export values—The *c.i.f.* or true market values—Comparison of the value of India's manganese-ore production with that of other minerals—The ferro-manganese value of the Indian manganese-ore production—Prices of ferro-manganese—Taking the ferro-manganese value, the Indian manganese-ore production for 1906 is about equal in value to that of coal—Enormous loss to India through not manufacturing ferro-manganese.

It will be interesting to see what is the total value of the manganese ore exported every year from India. There are of course several ways of stating the value. Manganese-ore possesses one value per ton as stacked at the pit's mouth, another as delivered *f.o.r.* at the railhead, a third as delivered *f.o.b.* on board the ship at the port of shipment, a fourth as delivered *c.i.f.* at the port of destination, and a fifth after it has been converted into ferro-manganese.

With the price at fourteen pence per unit the average value of Central Provinces' ore may be taken as :—

Rs.	*a.*	
19	10	at the pit's mouth.
21	2	*f.o.r.*
30	12	*f.o.b.*
43	12	*c.i.f.*

Official Indian statistics.

The question arises as to which of these values should be made use of in the compilation of the mineral statistics of India. The figures for the exports of manganese-ore for every year ending 31st March are given in the Annual Statements of Trade and Navigation of British India, and the export values of the ore are given also. These figures of values are much below the true export (or *f.o.b.*) values. In the Statistics of Mineral Production in India, issued annually, the export values of the ores are also given ; and as in the preceding case these are usually considerably less than the true export values. I do not know the exact way in which these figures are obtained, but I expect they are based on figures supplied by the mining companies exporting the ore. In the following table I give the values, stated both in rupees and in sterling, that have been given in the Statistics of Mineral Production in India from year to year.

TABLE 77.

Value of the Indian manganese-ore production as reported in the Statistics of Mineral Production.

Year.	TOTAL VALUE IN RUPEES.			Value in Sterling.	VALUE PER TON.		
	Central Provinces.	Madras.	Total.		Central Provinces.	Madras.	Average.
	Rs.	*Rs.*	*Rs.*	£	*Rs.*	*Rs.*	*Rs.*
1893		21,301	21,301	1,420		6·80	6·80
1894		77,651	77,651	5,177		6·80	6·80
1895		1,07,636	1,07,636	7,176		6·80	6·80
1896		3,87,022	3,87,022	25,801		6·80	6·80
1897		5,01,429	5,01,429	33,429		6·80	6·80
1898		4,11,386	4,11,386	27,426		6·80	6·80
1899		5,92,936	5,92,936	39,529		6·80	6·80
1900	5,30,340	6,29,223	11,59,563	77,304	15·00	6·80	9·07
1901	6,66,420	5,20,369	11,86,789	79,119	15·00	6·80	9·81
1902	13,94,135[1]	4,63,938	18,58,073	123,872	15·00	6·80	11·77
1903	15,23,310	4,67,807	19,91,117[2]	132,741	15·00	7·37	12·06
1904	[3]		19,44,480	129,632			12·94
1905	[3]		37,24,635	248,309			14·67
1906	[3]		65,29,020	435,268			13·17
Totals			2,04,93,038	1,366,203			

The *f.o.b.* or export value the true value to India.

It is a difficult question to decide which of the values noticed on page 529 should be taken as the true value of the Indian manganese-ore. The true market value is of course the *c.i.f.* value. But the proportion of this value that is made up of ocean freight and destination charges cannot be regarded, except in an indirect way, as of value to India. Hence I think the true value of the ore to India is the export or *f.o.b.* value; for all the expenses incurred in placing the ore at a port have benefited some one in India. The difference between the *f.o.b.* value and the cost of putting the ore *f.o.b.* a vessel at one of the ports is of course the profit to the mine owner. And this profit goes to companies or individuals working in India: and although it is true that a considerable proportion of these profits finds its way when distributed as dividends to people living out of India, yet it increases the capital of people interested in India, and so may be regarded as increasing the stock of capital available for use in this country. For these reasons, in the following tables, in which I have made an attempt to arrive at the approximate value

[1] The figure reported is 13,44,135, due to an error in calculating the value at Rs. 15 per ton.
[2] This total does not include Jhábua in Central India, which began to produce in this year.
[3] Values for the different provinces not reported separately, and only in sterling.

of the manganese-ore mined in India from the beginning of the industry in 1892 to the end of 1906. I have given the export values as being those that give the truest expression of the value of the manganese industry to India.

Tables of export value.

The calculation of these figures has, of course, been largely a matter of guess-work or estimation. For I have little information as to the prices mine owners have received from their ores from time to time nor as to the average composition of the ores exported from year to year. I have consequently had to take the quotations given in the Mining Journal and assume that these are the prices that have been obtained by the Indian manganese workers, modifying them where it seemed necessary: I have also had to assign to the ores of each area an average value for the manganese—and in the case of the lower grade ores for the iron—contents, this value being based on what I know of the composition of the ores of each area; but this figure is not necessarily the same as, though close to, the figures for each year on which the mine operator have been paid. Still I think that the errors are not as a rule serious, and that probably they more or less balance one another. Thus it is possible that I have sometimes allowed slightly higher prices for the Vizagapatam ores than have been obtained; whilst I know that in the case of the Central Provinces contracts have sometimes been made a long way ahead at times of low prices, so that it has not been possible for full advantage to be taken of the prices when they have risen. Other operators, on the other hand, have held back their stocks and never sold far ahead, so that they have been able to take a full advantage of the rises in price, as for example during 1906. Then, again, in some cases, ores that according to their manganese percentage should be graded as second or third grade ores, have been able at times of high prices and comparative famine in manganese-ore to fetch prices corresponding to the grade of ore above. I have allowed as far as possible for all these points: I have also allowed a price of 5 cents or 2½ pence per unit of iron, this being the American payment, in cases where I think that the price according to the grade of the ore for manganese alone, is lower than the ore probably fetched; but I do not know that any payment for iron has actually been obtained in these cases. I do not think it will be possible to compile such figures with greater accuracy unless the companies concerned are willing to divulge the average prices and percentages of manganese obtained on their cargoes from year to year. It is also to be noted that I have

assigned values to ores from Belgaum and Singhbhum although, as far as I am aware, none of the ore extracted in these two districts had been exported up to the end of 1906. The amounts of ore extracted in these two districts is, however small, so that the values of these ores do not make much difference in the totals. It is better to include the values of these ores under the years in which they were extracted, rather than when they were exported, so as to prevent confusion in the statistics.

It will be seen from the tables that the total export value of the ore mined in the Vizagapatam district during the 15 years 1892 to 1906 is Rs. 1,24,19,012 or £827,934, giving an average annual value of Rs. 8,27,934 or £55,196; whilst the total export value of the ore mined in the four districts of Bálághát, Bhandára, Chhindwára, and Nágpur, in the Central Provinces, during the 7 years 1900 to 1906, is Rs. 2,13,16,282 or £1,421,086, giving an average annual value of Rs. 30,45,183 or £203,012. The total export value of the Indian Production during these 15 years is Rs. 3,65,61,913 or £2,437,462. It has risen from Rs. 15,755 or £1,050 in 1892 to Rs.1,45,36,131 or £969,078 in 1906, with an average annual value for the whole 15 years of Rs. 24,37,462 or £162,497, and for the 7 years 1900 to 1906 of Rs. 45,26,276 or £301,752.

TABLE 78.

Export values of the manganese-ore produced in the Madras Presidency from 1892 to 1906.

Year.	District.	Assumed price per unit of 2nd grade ore. (1)	Assumed per cent. of Mn. and Fe. (2)	Value *c. i. f.* at U. K. ports.	Value *f. o. b.* at Indian ports. (3)	Production for year from tables Nos. 28 and 34.	TOTAL EXPORT (*f. o. b.*) VALUE.	
							In Indian currency.	In sterling.
		Pence.		*Rs. a.*	*Rs. a.*	*Long tons.*	*Rs.*	£
1892	Vizagapatam.	13	46 Mn	37 6	23 6	674	15,755	1,050
1893	Do.	12½	,,	35 15	21 6	3,130	66,904	4,460
1894	Do.	10	,,	28 12	14 12	11,410	1,68,297	11,220
1895	Do.	9½	,,	27 5	13 5	15,816	2,10,550	14,037
1896	Do.	11	,,	31 10	17 10	56,869	10,02,316	66,821
1897	Do.	10½	,,	30 3	16 3	74,467	12,05,435	80,362
1898	Do.	9½	,,	27 5	13 5	62,980	8,38,421	55,895
1899	Do.	10½	,,	30 3	16 3	84,652	13,70,304	91,354
1900	Do.	12	,,	34 8	20 8	92,008	18,86,164	125,744
1901	Do.	10½	,,	30 3	16 3	76,473	12,37,907	82,527
1902	Do.	9½	,,	26 9	12 9	68,171	8,56,398	57,093
1903	Do.	8½	,,	24 7	10 7	63,074	6,58,335	43,889
1904	Do.	8½	,,	24 7	10 7	53,602	5,59,471	37,298
1905	Sandur	8½	,,	23 11	9 11	1,200	11,625	775 } 41,972
	Vizagapatam	8½	..	23 11	9 11	63,789	6,17,956	41,197 }
1906	Sandur	11	..	31 10	17 10	3,209	56,559	3,771 }
	Vizagapatam	11	,,	31 10	17 10	72,315	12,74,552	84,970 } =114,212
	Do.	9½ (3rd grade)	37Mn. +15 Fe.	23 12	9 12	39,186	3,82,063	25,471 }
Totals and averages.		9·96d.		28 12	14 12	843,025 tons	Rs 1,24,19,012	£827,934

(1) 46% Mn. puts the Vizagapatam ores as 3rd grade. But they have often been much over 46 %, and probably always fetch 2nd grade prices, except the ferruginous ores entered separately under 1906.

(2) For the ferruginous manganese-ores—3rd grade—I have added on 5 cents=2½ annas per to a for each unit of iron.

(3) Obtained by subtracting Rs. 14 from the *c. i. f.* figures. In table 50 the cost of landing the ore *c. i. f.* at its destination is given as Rs. 14-12-0. But the average figure given for ocean freight is probably too high when applied to all the past years.

TABLE 79.

Export values of the manganese-ores produced in the Central Provinces from 1900 to 1906.

Year.	District.	Assumed price per unit of 1st grade ore.	Assumed per cent. of Mn.	Value per ton *c.i.f.* at U.K. ports.	Value per ton *f.o.b.* at Indian ports.[1]	Output for year from table No. 35.	TOTAL EXPORT (*f.o.b.*) VALUE.	
							In Indian currency.	In sterling.
		Pence.		*Rs. a.*	*Rs. a.*	*Long tons.*	*Rs.*	£
1900	Nágpur . .	14⅛	52	45 15	31 15	47,257	15,09,270	100,618
1901	Bálághát . .	11⅞	52	38 10	24 10	3,839	94,535	138,407
	Bhandára . .					499	12,288	
	Nágpur . .					76,925	18,94,278	
1902	Bálághát . .	10	52	32 8	18 8	1,975	36,538	93,923
	Bhandára . .					5,360	99,160	
	Nágpur . .					68,819	12,73,152	
1903	Bálághát . .	10½	52	33 5	19 5	7,898	1,52,530	138,982
	Bhandára . .					4,998	96,524	
	Nágpur . .					95,051	18,35,672	
1904	Bálághát . .	9¼	52	30 1	16 1	10,323	1,65,813	91,047
	Bhandára . .					8,559	1,37,479	
	Nágpur . .					66,142	10,62,406	
1905	Bálághát . .	9¼	52	30 1	16 1	16,246	2,60,951	162,281
	Bhandára . .					35,238	5,66,010	
	Nágpur . .					100,063	16,07,262	
1906	Bálághát . .	13½	52	43 14	29 14	102,260	30,55,017	700,828
	Bhandára . .					96,017	28,68,508	
	Chhindwára .					7,486	2,23,644	
	Nágpur . .					146,117	43,65,245	
		average		average	average	901,072		
Totals and averages.		11·58*d.*		*Rs. a.* 37 10	*Rs a.* 23 10	tons.	Rs.213,16,282	£1,421,086

[1] Calculated from the *c. i. f.* value by subtracting Rs. 14. This is a little more than the cost of ocean freight *plus* destination charges (Rs. 13-4) as given in table 50, and may be considered to allow for the fact that some of the ore goes to America, whilst a little is exported through Calcutta.

TABLE 80.

Export values of the manganese-ores produced in Bengal, Bombay, Central India, and Mysore, from 1903 to 1906.

Year.	Province.	District or State.	Assumed price per unit of Mn. 1st grade ore.	2nd grade ore.	3rd grade ore.	Assumed per cent. of Mn. and Fe.	Value per ton *c.i.f.* at U. K. ports.	Value per ton *f.o.b.* at Indian ports.[1]	Production for year from table 24.	Total export (*f.o.b.*) value. In India currency.	In sterling.
			Pence.	*Pence.*	*Pence.*		*Rs. a.*	*Rs. a.*	*Long tons.*	*Rs.*	£
1903	Central India	Jhábua .	..	9	..	47Mn.	26 7	12 7	6,800	84,575	5,638
1904	,,	,,	..	9	..	47Mn.	26 7	12 7	11,564	1,43,827	9,588
1905	Bombay	Belgaum.	..	..	7	45Mn.+10Fe	21 4	7 4	40	290	19
1906	Central India	Jhábua .	..	8½	..	47Mn.	23 8	9 8	30,251	2,87,384	19,159
	Bengal	Singhbhum	.	12	.	47Mn.	35 4	21 4	1,000	21,250	1,417
	Bombay	Belgaum.	..	..	9¼	45Mn.+10Fe	27 9	13 9	234	3,174	212
	,,	Panch Mahals.	13½	..	..	50Mn.	42 3	28 3	7,286	2,05,374	13,692
	Central India	Jhábua .	..	12	..	47Mn.	35 4	21 4	50,074	10,64,072	70,938
	Mysore	Shimoga.	..	12	..	48Mn.+10Fe	37 9	23 9	40,773	9,60,714	64,048
	..	Tumkur .	..	..	9¼	45Mn.+10Fe.	27 9	13 9	4,126	55,959	3,731

[1] Obtained by subtracting Rs. 14 from *c.i.f.* values, as in preceding tables.

TABLE 81.

Export values in Rupees, f.o.b. at Indian ports, of the manganese-ore produced in the various Provinces of India from 1892 to 1906.

	Bengal.	Bombay.	Central India.	Central Provinces.	Madras.	Mysore.	Totals.
	Rs.	*Rs.*	*Rs.*	*Rs.*	*Rs.*	*Rs.*	*Rs.*
1892					15,755		15,755
1893					66,904		66,904
1894					1,68,297		1,68,297
1895					2,10,550		2,10,550
1896					10,02,316		10,02,316
1897					12,05,435		12,05,435
1898					8,38,421		8,38,421
1899					13,70,304		13,70,304
1900				15,09,270	18,86,164		33,95,434
1901				20,01,101	12,37,907		32,39,008
1902				14,08,850	8,56,398		22,65,248
1903			84,575	20,84,726	6,58,335		28,27,636
1904			1,43,827	13,65,658	5,59,471		20,68,956
1905		290	2,87,384	24,34,223	6,29,581		33,51,478
1906	21,250	2,08,548	10,64,072	1,05,12,414	17,13,174	10,16,673	1,45,36,131
Totals	21,250	2,08,838	15,79,858	2,13,16,282	1,24,19,012	10,16,673	3,65,61,913

TABLE 82.

Export values in Sterling, f.o.b. at Indian ports, of the manganese-ore produced in the various Provinces of India from 1892 to 1906.

	Bengal.	Bombay.	Central India.	Central Provinces.	Madras.	Mysore.	Totals.
	£	£	£	£	£	£	£
1892					1,050		1,050
1893					4,460		4,460
1894					11,220		11,220
1895					14,037		14,037
1896					66,821		66,821
1897					80,362		80,362
1898					55,895		55,895
1899					91,354		91,354
1900				100,618	125,744		226,362
1901				133,407	82,527		215,934
1902				93,923	57,093		151,016
1903			5,638	138,982	43,889		188,509
1904			9,588	91,047	37,298		137,933
1905		19	19,159	162,281	41,972		223,431
1906	1,417	13,904	70,938	700,828	114,212	67,779	969,078
Totals	1,417	13,923	105,323	1,421,086	827,934	67,779	2,437,462

The values given here are the export values. But it must be remembered that the true value on the world's markets is the *c.i.f.* value. This can be obtained from the *f.o.b.* figures by the addition of Rs. 14 per ton. This gives the total annual values of the Indian production for the last seven years shown below :—

The *c.i.f.* or true market values.

TABLE 83.

Values in sterling c.i.f. at destination of the manganese-ore produced in India from 1900 to 1906.

Year.	Rs.	£
1900	53,45,141	356,343
1901	54,47,312	363,154
1902	42,85,798	285,720
1903	53,17,130	354,475
1904	41,71,656	278,110
1905	68,15,456	454,364
1906	2,25,37,061	1,502,471
Average annual value	77,02,794	513,520
Total value for the 7 years	5,39,19,557	3,594,637

Comparison of India's manganese-ore production with that of other minerals.

We can now compare the value of India's manganese-ore production with that of her other mineral products. Taking the export or *f.o.b.* values of the Indian manganese-ore, and comparing them with the values for the other chief Indian minerals as given in the annual statistics of Mineral Production[1], we see that in 1903, 1904, and 1905, manganese-ore was the sixth in value, being surpassed by gold, coal, petroleum, salt, and saltpetre, in the order named. But in 1906 manganese-ore jumped up to the third position, being surpassed only by gold and coal. The figures are shown in the following table :—

TABLE 84.

Values of the 8 chief mineral products of India for the years 1903 to 1906.

	1903.	1904.	1905.	1906.
	£	£	£	£
Gold	2,303,144	2,366,079	2,416,971	2,230,284
Coal (*a*)	1,299,716	1,398,826	1,419,443	1,912,042
Manganese-ore (*b*) . .	188,509	137,933	223,431	969,078
Petroleum (*a*) . . .	354,365	473,971	604,203	574,238
Salt (*a*) . . .	336,147	437,530	441,392	420,901
Saltpetre (*b*) . . .	290,196	266,349	235,723	270,547
Mica (*b*)	86,296	97,932	142,008	259,544
Rubies	88,819	90,612	88,340	96,867

(*a*) Spot prices ; (*b*) Export values.

The above figures give roughly the relative values of the respective minerals to India ; but they do not give the true relative values of these minerals on the world's markets. The true values of the minerals are the values at the places where the minerals are to be used. The gold is, of course, appraised at its true market value. If the other substances

[1] *Rec. G. S. I.*, XXXIII, p. 3, (1906) ; XXXIV, p. 47, (1906) ; XXXVI, p. 65, 907).

were given their true market values where used, the true order of value of the first constituents would probably be found to be coal, petroleum, gold, manganese-ore, salt, and saltpetre. If we take the mineral production for 1906 and give the following values :—coal Rs. 7-8 per ton, petroleum 5 annas per gallon, salt spot price (avoiding duty), saltpetre 18*s.* 6*d.* per cwt. *c.i.f.* value [1], manganese-ore its *c.i.f.* value, and mica its *f.o.b.* value [2], the following are the values of the eight chief mineral products :—

	£
Coal	4,891,625
Petroleum	2,928,190
Gold	2,230,284
Manganese-ore	1,502,471
Salt	420,901
Saltpetre	321,207
Mica	258,782
Rubies	96,867

The ferro-manganese value of the Indian manganese-ore production.

Even the comparison of the *c.i.f.* value of manganese-ore with the market values of the seven other mineral products noticed above, is not a fair one, for the reason that the *c.i.f.* value of manganese-ore is the value of the substance only before it is ready for use. Coal needs no working up, except when it is to be converted into coke, and is ready as soon as mined for the purpose for which it is used, namely as fuel. The petroleum is valued after it has been sufficiently refined and is ready for lighting purposes and as a fuel. The salt and saltpetre are valued after being refined, so as to be ready for human consumption and the manufacture of gunpowder, respectively. The mica when valued has been separated from its matrix and cut into shapes and sizes and is ready for use, except in the case of the scrap from which micanite is manufactured. The rubies have been separated from their accompanying minerals and need no further treatment except cutting. The gold is only in the form of bullion; but it is given practically its full value and has been won from its ore after complex metallurgical treatment. For the value of the manganese-ore to be fairly comparable with that of the other constituents it should therefore be valued after it has been converted into ferro-manganese,

[1] The mean of the prices quoted during 1906 for crude saltpetre in the Engineering and Mining Journal.

[2] I have given the *f.o.b.* value of the mica because I do not know the cost of sending it to Europe. This can form only a small portion of the total value of the mica, however, so that the *f.o.b.* value is not much less than the *c.i.f.* value.

that is after the metallic manganese has been separated from its accompanying constituents in the same way as the gold has been separated from its gangue.

Of course, all the Indian manganese-ore is not converted into ferro-manganese ; but as it is not possible for me to say what proportion of it is converted into spiegeleisen, and what proportion is used in other ways ; and as it all could be converted into ferro-manganese we shall obtain the best idea of the potential value of the Indian manganese-ore, by supposing it all to be converted into ferro-manganese. In table 85 I give the weekly prices quoted in the *Engineering and Mining Journal* of New York from 1901 to 1907 ; the volumes of this journal for years previous to 1902 are not in the library of the Geological Survey of India, and so I cannot give the quotations previous to 1901. From the table it will be seen that the quotations vary between $41 in May 1904, and $150 in February 1906, with a mean for the whole period of $61·39[1]. It will be noticed on comparing this table with table 27 on page 415 showing the variations in the price of manganese-ore from 1900 to 1907, that the price of ferro-manganese varies more or less in sympathy with that of manganese-ore, though the two are not strictly proportional. Hence as the prices for manganese-ore were on the average higher during the years 1892 to 1900 than in the succeeding years, we should probably not be over-estimating the average price of ferro-manganese during these years if we applied the same average as for the 7 years 1901 to 1907. But to be quite sure of not over-estimating let us take $50, or, say, £10 or Rs.150, as the average price per ton during the years before 1901. In table 86 I give (1) the annual totals for Indian manganese-ore production, (2) the number of tons of ferro-manganese they would give on the assumption that two tons of Indian manganese-ore would be required for the production of 1 ton of 80% ferro-manganese (allowing for a loss of 20% of the manganese in the smelting), (3) the average price of ferro-manganese per ton assumed for each year, and, finally, (4) the total value of the Indian ferro-manganese that could have been manufactured from the Indian manganese-ore produced each year. The fact that some of the Indian ore would not give as high grade ferro-manganese as 80% is more than neutralized by the fact that I have probably underestimated the price of ferro-manganese for the years previous to 1901.

Prices of ferro-manganese.

[1] In December 1905 one car-lot was sold for $175.

TABLE 85.

Average prices per ton, at Pittsburg, United States of America, of 80 per cent. ferro-manganese for the years 1901 to 1907.

	1901	1902	1903	1904	1905	1906	1907
	$	$	$	$	$	$	$
January	62·50	52·50	51	46	45	135	81
February	62·50	52·50	50	44	46	150	74
March	62·50	52·50	50	43	47	140	75
April	58·50	52·50	50	42	51	125	71
May	58·50	52·50	50	41	50	105	69
June	58·50	52·50	50	41	50	90	64
July	53·50	51·50	50	41	50	85	63
August	53·50	52·50	49	41	50	85	62
September	53·50	52·25	48	41	54	83	58
October	53·50	51·25	48	41	62	78	57
November	53·50	52·50	48	42	100	82	53
December	52·50	51·00	47	42	125	83	52
Average for year	56·92	52·17	49·25	42·08	60·83	103·42	64·92

NOTE.—Taken from the first number of the *Engineering and Mining Journal* of each year. Figures for 1902 compiled from the weekly quotations in this journal, the first number for this year being missing from the Geological Survey Library. Figures for 1907 compiled in same way. In most cases the prices represents 'domestic' ferro-manganese, i.e., made in United States of America; but sometimes quotations of English and German ferro-manganese have been used to fill up blanks. They never vary greatly from the domestic quotations.

TABLE 86.

Value of the Indian manganese-ore production from 1892 to 1906, when converted to ferro-manganese.

Year.	Total annual Indian manganese-ore production.	Equivalent amounts of 80% ferro-manganese.	Average annual price of ferro-manganese per ton.	ANNUAL VALUES OF FERRO-MANGANESE EQUIVALENTS OF THE MANGANESE-ORE.	
				In Indian Currency.	In sterling.
	Long tons.	Long tons.	£	*Rs.*	£
1892	674	337		50,550	3,370
1893	3,130	1,565		2,34,750	15,650
1894	11,410	5,705		8,55,750	57,050
1895	15,816	7,908		11,86,200	79,080
1896	56,869	28,434	10	42,65,100	284,340
1897	74,467	37,234		55,85,100	372,340
1898	62,980	31,490		47,23,500	314,900
1899	84,652	42,326		63,48,900	423,260
1900	139,265	69,632		1,04,44,800	696,320
1901	157,736	78,868	10·8	1,27,76,610	851,774
1902	144,325	72,163	10·3	1,11,49,185	743,279
1903	177,821	88,910	9·55	1,27,36,350	849,090
1904	150,190	75,095	8·5	95,74,605	638,307
1905	247,427	123,714	16·95	3,14,54,280	2,096,952
1906	571,495	285,747	17·4	7,45,79,970	4,971,998
Totals	1,898,257	949,128	13·06 (average)	18,59,65,650	12,397,710

For the average annual price of ferro-manganese given in the fourth column, I have not taken the averages given in table 85:

instead of this I have taken averages based on the last nine months of a given year and the three first months of the next. This is to allow for the fact that a certain time must elapse between the despatch of the ore from the mines and its conversion into ferro-manganese in America or Europe; so that ferro-manganese made from ore exported during a given year would come on to the market in time for the prices obtaining during the last nine months of that year and the first three of the next year. From this table it will be seen that the value of the ferro-manganese equivalent of the manganese-ore produced in 1906 was nearly five million sterling or 7½ crores of rupees. This valuation actually places manganese-ore at the head of the list of India's mineral products for 1906.

Taking the ferro-manganese value, the Indian manganese-ore production is about equal in value to that of coal.

But the value given above for coal in this year is very little less than that of the manganese: and hence as both valuations are based on assumptions it is better to say that the ferro-manganese value of India's 1906 production of manganese-ore is about equal to the true value of the coal.

The chief interest of these figures does not, however, lie in the position they give to the Indian manganese-ore production relative to that of the other Indian mineral products; but in the enormous financial loss they show that India suffers by the export of its manganese-ore in the raw condition. Because the ore is exported in this condition the total value of the Indian manganese-ore production since 1892 to 1906 has been worth to India only 3 crores and 5 lakhs of rupees, or about £2,437,000. Whilst, if this ore had been converted into ferro-manganese in India, the least value to India would have been the export value of the ferro-manganese produced. The export value of the ferro-manganese is its market value where it is to be used *minus* the expenses incurred in getting it to these markets, on the assumption that none of it remains in India for home consumption. £1 or Rs. 15 may be taken as a fair average for the expenses that would be incurred in putting the ferro-manganese manufactured in India on the European and American markets. Making this deduction per ton from the values given in table 86 we see that the export value of the ferro-manganese for the whole period of 15 years would have been Rs. 17,17,28,730 or £11,448,582. Instead of this

Enormous loss to India through not manufacturing ferro-manganese.

the export value of the manganese-ore, since it was exported in the raw condition, was only Rs. 3,65,61,913 or £2,437,461; from which we see that India has suffered a loss of Rs. 13,51,66,817 or £9,011,119, or, say, roughly 13½ crores of rupees or 9 millions sterling, during the 15 years 1892 to 1906, through not manufacturing ferro-manganese in the country. The loss for the year 1906 alone may be put at 6 crores of rupees or 4 millions sterling; and for the present year (1907), in which prices for ferro-manganese rule lower, the loss calculated in this way will probably not be less than 1½ to 2 millions sterling.

The above potential losses considerably overstep the mark, however, for the reason that if all the manganese-ore mined in India were worked up in the country into ferro-manganese, the demand for the ferro produced would not be as great as it is at present for the manganese-ore. For those countries in which there are furnaces set aside for the manufacture of ferro-manganese would, if deprived of their Indian supplies of manganese-ore, do their best to obtain the ore required from other countries, such as Russia; for the steel companies naturally prefer to make their own manganese-ore and secure the profits on its manufacture, to buying the substance ready-made, when the profits go to some one else. There are, however, many steel manufacturers who do not manufacture their own ferro-manganese, and these would no doubt be willing to buy Indian ferro-manganese if the price were favourable as compared to that of ferro from other sources. Hence we see that the true potential loss is less than given in the preceding paragraphs; but how much it is impossible to say.

In any case the potential loss to India through ferro-manganese not being made in the country is so large, that the enormous exports of manganese-ore year by year cannot be a matter of congratulation to the country. For although they mean employment to some 10,000 coolies, a considerable number of cartmen, a small number of skilled workmen and mining men, and a considerable income to the railways and mine owners, yet each ton of ore that goes out of the country means the loss of a certain amount of employment to men who might be employed in the smelting of the ore into ferro-manganese. Further, each ton of ore that goes out of the country means a smaller amount of ore left against the time when the iron and steel industry becomes a large and flourishing one in India. It would be a great pity, considering how excellently India has been endowed by Nature with many of the materials—iron-ore, manganese-ore, chrome-ore, and wolf-

ram,—needed in the modern processes for the manufacture of iron and steel, if, when the time came for iron and steel to be manufactured in the country, it were found that all the subsidiary minerals—manganese-ore, chrome-ore, wolfram, etc.,—had been exported from the country, so that the manufacturer had to import these materials from other countries.

I do not want to take up an alarmist position; for there can be no doubt that India has enormous supplies of manganese-ore. Still if the export of this commodity continues at the present rate, the next 20 to 30 years will see the exhaustion of a very large number of deposits, at least as regards high-grade ores. Some deposits already show signs of exhaustion and every year will see more deposits put on to the list of defunct. Fortunately, however, there are signs that the Indian iron and steel industry will get into full swing in the next 10 years, so that it may be in time to take advantage of the existence of manganese-ores in this country. But in the course of the next 20 or 30 years either metallurgical practice will have to be improved so that lower grade and more siliceous ores can be utilised; or, secondly, mechanical processes for concentrating and improving these lower grade siliceous ores will have to be adopted; or, thirdly, the continuity in depth of the high grade ores of the Central Provinces will have to be proved by boring or actual mining; otherwise the Indian manganese industry will probably come to an end. In the third case the supply of high grade ores would be ensured for a considerably longer period than the 20 to 30 years—which is only a guess—mentioned above. With regard to the possibility of manufacturing ferro-manganese in India see page 585.

One reason for not advocating at present any restrictions on the export of manganese-ore is that the metallurgy of iron and steel progresses at such a rate that one cannot be certain that the use of manganese may not one day be discontinued in favour of some more efficient substance; or that steel may not be made by some new process in which there is no need for manganese or any substance performing similar functions.

CHAPTER XXVI.

ECONOMICS & MINING—*continued.*

The Mining or Quarrying of Manganese-ores.

General principles for deciding whether to mine or quarry a deposit—Mode of occurrence and structure of the deposit—Depths to which manganese-ore deposits extend—Relation of the outcrop of the deposit to the topography—The value of the ores—Nature of the 'country' of the deposits—The presence of water—Cost of timber, tools, and plant—Cost of labour—Cost of employing technically-trained managers.

The way to prospect a manganese-ore deposit.

The way to work a manganese-ore deposit—Four mistakes to be avoided—Thick ore-band of moderate dip forming a hill—Thick ore-band of steep dip forming a hill—Thin ore-band in a hill—Thick ore-band cropping out on low ground—Thin ore-band cropping out on low ground—Scattered ore-bodies in lithomarge—Lateritoid cappings—Deposits of detrital ore or talus-ore.

To mining men the larger part of this chapter will probably seem trite and unnecessary and out of keeping with the character of the remainder of this Memoir, so that an apology for its introduction is perhaps desirable. Now it so happens that there are a large number of people engaged in the Indian manganese industry who have had no previous acquaintance with mining, and consequently in most cases do not recognize the complexity of the problem of working even such an apparently simple thing as a manganese-ore deposit; according to popular notions, in fact, one has only to dig out the ore, send it to the markets, and draw in the profits. I hope the first section of this chapter will open the eyes of such people and show both them and any other laymen who contemplate taking a part in the Indian manganese industry that to get the best results, and indeed any that are not much below the best, it is necessary to employ men who by training are qualified to deal both with the considerations put forward in this section and with many others not mentioned here.

In the section on the way to prospect a manganese-ore deposit, I propose to give a few hints as to the best way in which to obtain some idea of the value of a deposit when found. My object is that if a layman attempt to open up a deposit without proper advice, as is bound frequently to happen, his attempts shall be made on some reasonable basis

so that these preliminary workings shall not be carried out to the detriment of the deposit, and force the technically-trained man, when he comes on the scene, to spend a considerable portion of his time for some months in cleaning up the deposit before he can begin to work it in a systematic way.

In the third section—on the way to work a deposit—I propose to indicate roughly the outlines of the methods that it seems to me could be adopted with the best advantage when it comes to actually working the deposits. I have not gone into any details, both on account of the space it would take up and because each deposit is really a problem in itself with regard to details. This section will, I hope, be of use even to the qualified miner; for on coming to a new country he is not likely to be able to grasp at once the true structure and mode of occurrence of the deposits, and his employers are not as a rule likely to let him sit down and find this out in a satisfactory way, unless he can contrive to do it in company with a large output of ore, and a small expenditure. The figures illustrating this section practically all represent, as regards mode of occurrence, deposits that actually exist.

General Principles for Deciding whether to Mine or Quarry a Deposit.

It may be laid down as an axiom that in working any given mineral deposit that method should be chosen that will give the maximum profit per ton of ore extracted; the profit being of course, in the case of ores that are exported in a raw condition, the difference between the total costs of extracting the ore and putting it on the market, and the price it will fetch on that market; or, in the case of ores that are to be smelted or otherwise worked up on the spot, the difference between the total costs of extraction, smelting or preparing, and transporting to the market, and the price the treated product will fetch when it reaches the market.

In calculating the maximum profit obtainable from a given deposit, however, it is necessary to consider the whole of the merchantable ore that the deposit may be known to contain, or that it is possible that future development may prove it to contain; that is, it is necessary to consider the life of the deposit.

Now the chief factors that have to be considered in deciding in what way to open up a given deposit are the following:—

(1) The mode of occurrence and structure of the deposit.

(2) The relation of the deposit to the topography.

(3) The value of the average ores of the deposit, and of the best ores.
(4) The character of the 'country' of the deposit, as regards both the soundness of the rock and the abundance of water.
(5) The costs of mining materials, such as timber, tools and plant, when delivered at the mine.
(6) The cost of labour, both local and imported.
(7) The cost of employing men with knowledge sufficient to develop the deposit in the way proposed.

The two chief methods of working a mineral deposit—leaving out of account detrital and alluvial deposits, which may be treated by dredging, hydraulicking, etc.,—are :—

(*a*) Opencast working, or quarrying.
(*b*) Underground working, or true mining.

We can now consider the influence of each of the above factors in determining the way in which manganese-ore deposits in general, and the Indian manganese-ore deposits in particular, should be worked.

Mode of occurrence and structure of the deposit.

1. It is obvious that if the body or bodies of ore lie at or close to the surface, with no or very little overburden, opencast work, or quarrying, is all that will be necessary. If, however, the ore-body, in the form of either bed, lenticle, vein, or irregular mass, extend to some considerable depth, it will be necessary to resort to the methods of underground mining to win, at any rate the deeper portions of, the ore. If it be decided that it will pay to win the ore lying below the depth to which opencast working can be carried, it will be necessary to decide whether the whole of the ore-body is to be mined, or whether the upper portion is to be quarried and the lower mined.

It is also obvious that before any proper decision can be reached on these points it is necessary to know something about the structure of the deposit. This can of course be obtained only by testing the deposit, first by means of surface prospecting, involving the digging of surface cross-cuts or costeans, and trial pits ; and then, if the ore be found to go to as great a depth as can be conveniently reached by these methods, by putting down shafts or bore-holes.

Depths to which manganese-ore deposits extend.

It has yet to be proved that deposits of manganese-ore extend to a greater depth from the surface than a few hundred feet, say 300 to 500 feet (many of course do not extend to greater depths than 50 feet

or less). In fact the mining and quarrying of manganese-ore deposits in different parts of the world has shown that the deposits of oxide-ores have been formed, in the majority of cases, at or close to the surface, and do not extend to any considerable depth, say beyond 50 to 500 feet. It is to be noted, however, that if any portions of the ores of the Central Provinces of India can be considered as the product of the direct compression of original manganese-oxide sediments, then such portions may be found to continue to as great a depth as the associated rocks of the gondite series, and this may be in some cases considerably more than 300 to 500 feet. The same remarks apply to any other deposits, such as those of Sweden, that have been formed by the direct compression and metamorphism of original manganese-oxide sediments, without any passage through a silicate stage with subsequent chemical alteration. (The franklinite deposits of New Jersey in America, in which the franklinite, a manganese-zinc-iron mineral, is regarded by some as having been formed by the metamorphism of original sediments containing both manganese and zinc, and which has been proved by boring to continue to depths of over 1,000 feet, may be cited as an example of a manganese-oxide mineral proved to continue to a great depth.)

Even on the assumption that none of the Indian deposits will be proved to continue to a greater depth than 300 to 500 feet below the original outcrop, there is still plenty of scope for true mining ; namely, between the depths of 50 to 100 feet and 300 to 500 feet. Before passing on to the next section I will state the depths to which the Indian manganese-ore deposits have been proved, and may be expected to continue.

TABLE 87.

Depths to which Indian manganese-ore deposits extend.

Area.	Depth to which proved.	Depth to which may be expected in some cases to continue.	Depth to which possibly in some cases continue.
	Feet	Feet.	Feet.
Central Provinces . .	80	150—200	300—500, or more.
Vizagapatam . . .	100	150—200	300—400
Sandur	50	80	100
Mysore	30	60	80

The figures given in the first column refer only to the larger deposits. In some cases in each area deposits have been found not to continue even to the depths given in this column. Those in the second column

also apply to the larger deposits in each area, such as Kándri, Kodur, Durgámma Kolla, and Kumsi, typical of each of the four areas mentioned. The figures given in the third column may be regarded as the probable outside limits to which the most extensive deposits in each area may possibly extend. It must be remembered, however, that these figures are based on theoretical guesses, in the absence of any bore holes or shafts proving the deposits to continue to any greater depths than in the first column.

Relation of the outcrop of the deposit to the topography.

2. The position of the outcrop of the deposit with regard to the topography of the surface is also a matter of some importance. Thus it might be possible to work a deposit outcropping on a hill 200 feet high with reference to the surrounding plains, and proved by boring or other methods of prospecting to continue to a depth of 200 feet from the top of the outcrop, entirely by opencast work, given favourable circumstances as to the nature of the 'country' : whilst a deposit, the top of which only just appears above the surface of plain country, and also proved to extend to a depth of 200 feet below the outcrop, could be worked by opencast work to a depth of some 100 feet only, except by carrying out an enormous amount of deadwork ; in fact, except at enormous expense, or in most exceptional circumstances, it would be necessary to resort to mining to extract the second hundred feet of ore.

The value of the ores.

3. If an ore deposit extend to a considerable depth so that deep mining will be necessary to win all but say the top 100 feet of it, then the value of the deeper ore decides whether it will pay to follow it to this depth. It has already been noticed that in all probability deposits of manganese-oxide ores, with possibly a few rare exceptions, do not extend to greater depths than 50 to 500 feet. And it is doubtful, considering the comparatively low market value of manganese-ore, whether it would pay to follow a manganese deposit below the depth of 300 to 500 feet, even if it continued. The necessary conditions for it to be workable below this depth would probably be that the deposit should be a thick, regular deposit of high-grade ore situated close to the smelting centres. But let us confine ourselves to ores lying at depths less than this 300 to 500 feet. It is obvious that the average quality of the ore would have a considerable bearing on the possibility of extracting that portion lying at depths greater than 50 to 100 feet. Thus near the surface with favourable conditions it might easily be possible to extract ore of very low grade, say 20 to 30 per cent. of manganese, and treat it mechanically so as to concentrate

it up to a marketable grade: whilst at depths below this 50 to 100 feet, but otherwise under the same conditions, it might not be possible to work ore that was not of fairly high grade, and required mechanical treatment to render it marketable. Some manganese-ore deposits contain bands of ore requiring mechanical treatment to render them fit for the market, alternating with bands of ore not requiring such mechanical treatment. In such a case if an average sample of the whole width of the ore-body were taken at a depth of 100 feet, the assay result might indicate that the deposit could not be profitably worked at such a depth. Whilst if the poor and rich ore were analysed separately it might turn out that it would pay to work the deposit at this depth by rejecting the lower grade ore. It is possible to imagine the case of two manganese-ore deposits, the average ore of which taken from a depth of 100 feet assayed 35 per cent. manganese in each case. But on account of the ore of one being uniformly of 35 per cent. grade throughout, a considerable proportion of the remainder being quartz, it might be unprofitable to work it, on account of the cost of treating the ore mechanically in order to fit it for the market. On the other hand, the other deposit, being composed of bands of ore of variable composition, some as high as 50 per cent. manganese, and some as low as 20 to 30 per cent. manganese, might possibly be workable at a profit by saving only the higher grade ore, and rejecting the remainder, so as to avoid the cost of mechanical concentration.

Nature of the 'country' of the deposit.

4. The character of the 'country' or enclosing rock of the ore deposit is also a matter of considerable importance. In cases where it is extremely soft and wet, as in the case of the lithomargic 'country' of Kodur and other mines in the Vizagapatam district, it might be a matter of extreme difficulty and danger, with very high working costs, to mine the deeper portions of the deposit: whilst on account of the extreme softness of the 'country' it might be possible, by carrying out an enormous amount of deadwork, to work opencast to a much greater depth than would be possible with hard 'country', at a cost much lower than that of true mining; the quarry would be very much wider than the width of the ore-body, and would have its sides stepped on account of the softness of the 'country'; and the soft 'country' would be removed in slices as the quarry was constantly deepened. Such is the practice that has been followed in the case of the Kodur quarry in Vizagapatam, which has now reached a depth of about 100 feet below the original surface of the plains. Such a method of work

would, however, be prohibitive in cost and unnecessary, were the 'country' hard and sound. On the other hand, the soundness of the ground would reduce the cost of true mining on account of the smaller cost of timbering required, and might make mining cheaper than quarrying.

The presence of water in a deposit is also of great importance. One of the reasons why it is possible to work to greater depths opencast on a deposit situated on a hill, than on a deposit the top of which is only at plains level, is that the former deposits are usually comparatively dry, and if not they can be easily rendered so by the construction of drainage adits driven into the side of the hill. Pumping, when necessary, may be a serious item in the total costs of mining.

The presence of water.

5. In cases where it is doubtful whether to quarry or mine a deposit the relative costs of the tools and plant required in the two cases, and the cost of the timbering that may be required in case underground mining is resorted to, have to be considered.

Cost of timber, tools and plant.

6. When labour is very cheap it may often be advisable to work a deposit in a simpler way and with less labour-saving apparatus than would be desirable in the case of dear labour. India is a country of cheap labour. But it must be remembered that besides the cheapness of labour, as measured by the wages per head paid, the efficiency and abundance of the labour has to be considered. Though the amount of ore or coal excavated per man per day is considerably less in India than with European labour in colder climes, yet the greater expense of the white labour probably overbalances the extra efficiency. [In coal mining it is probable that no country works more cheaply than India.] Further, if a supply of labour cannot be obtained sufficient to keep a mine in full swing, as often happens in some of the manganese-mining districts of India, then in spite of the relative cheapness of such labour as is obtainable it may still be desirable to make use of as much labour-saving apparatus as possible. In considering the respective merits of quarrying and mining in the case of a deposit extending to such a depth that it might be treated in either way, it has to be remembered that for underground work a greater proportion of skilled labour is necessary than for opencast work. It then usually happens that the labour for underground work has to be trained, or to be imported from elsewhere at a higher rate than would obtain for local labour employed for opencast work.

Cost of labour.

Cost of employing technically-trained managers.

7. A further point that has to be considered is that opencast work can be carried out with a smaller amount of skilled supervision than underground mining. In fact it is often the custom in India—though this is most undesirable from the point of view of the life of the deposit, and therefore of the good both of the country and of the individual or company to whom the country has entrusted the development of the deposit—to open up a deposit, extract the ore in large quantities, and export it, without having any technically-trained man or men to superintend and direct the work.

Without the technically-trained men noticed under heading 7, it is of course impossible for the licensee or lessee of a property to ascertain anything accurate about the mode of occurrence of his deposit, and about its structure, and therefore impossible to work the deposit in the most advantageous way.

The Way to Prospect a Manganese-ore Deposit.

Let us suppose that one has found a loose piece of manganese-ore either in a stream-bed or on a hill-side. One goes of course upstream, or uphill, as the case may be, to see where the fragment has come from. As likely as not the prospector will be rewarded by finding other pieces of ore in increasing quantities, and will finally arrive at an outcrop of manganese-ore *in situ*. This outcrop may be an isolated one projecting through alluvium or soil, and showing no indications of strike or dip, *e.g.*, O in figure 28. The soil should then be removed to a depth

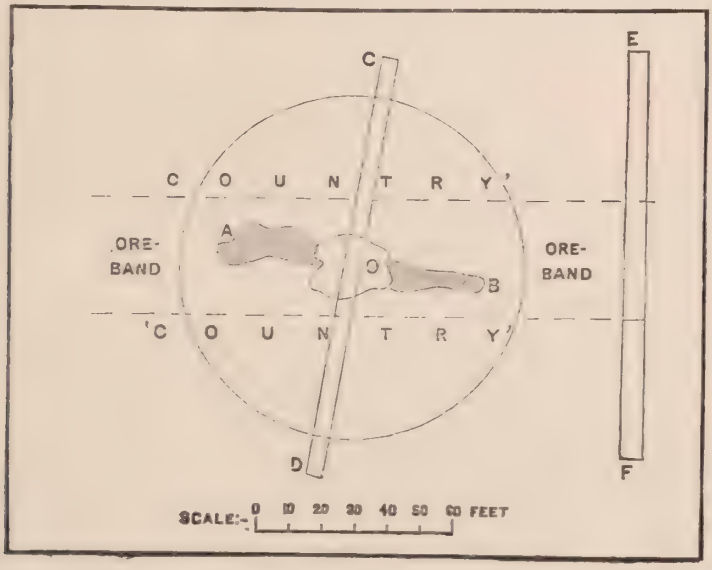

Fig. 28.—Prospecting an outcrop on low ground

of a few feet, for a distance of some yards in all directions round the deposit, such as up to the circle in the figure. Further indications of ore will then probably be found, such as the cross-hatched areas in figure 28. These will probably show some signs of direction; in the figure they indicate a strike AB. A trench, CD, should then be dug at right angles to this supposed strike, and carried down to a depth sufficient to show both the full width of the ore-body, and its contact with the 'country' or enclosing rocks. From the boundaries of the ore-band as seen in the trench, it will probably be found that this first trench has not been dug exactly at right angles to the strike of the ore-body, but askew. Another trench, such as EF in the figure, should then be constructed in a direction at right angles to the supposed strike of the ore-body, and for the purpose of testing the extension of the ore-body in this direction. It will probably be found necessary to dig this trench deeper than CD in order to reach rock *in situ*, for, as likely as not, the original outcrop corresponds to a small hill or hillock submerged in the alluvium. With this second trench the true strike of the ore-body should be ascertained; and the width of the deposit will now be known at two points. The extension in both directions should now be tested by further trenches both to the right and left of the original ones.

Possibly, however, there may be several small outcrops ranged along a low ridge some 30 to 100 feet high, or along a higher range or hill from 100 to 300 or even 500 feet high. In this case the length of the ridge probably corresponds with the strike of the ore-body, at least roughly. Figure 29 may be taken to represent a ridge about 100 feet high, showing

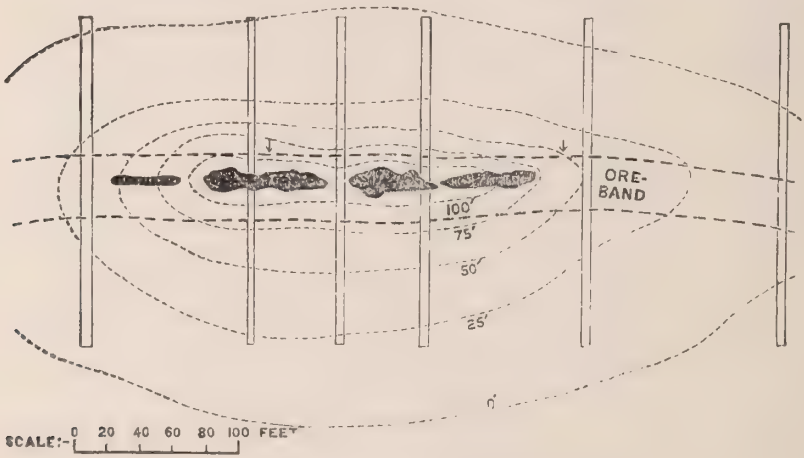

Fig 29.—Prospecting an outcrop along a ridge

several small outcrops (black) arranged along the crest of the ridge. Possibly the outcrops will show signs of a dip, if the ore-body be a sheet-like mass. Whether it does or not a series of trenches should be cut across the ridge at regular intervals. There is no necessity to carry them down to the level of the plain round the hill, but they should be carried down deep enough to reach rock everywhere. From this series of trenches it will be possible to ascertain the true strike of the ore-body, its dip—probably varying from point to point—, and the width at several points, from which an average of some value can be struck. Other trenches should be put across the assumed extension of the deposit on the plains at either end of the ridge to test the continuation of the deposit in both directions. One of the trenches on the hill itself might be cut down to a depth of at least 30 feet, in order to show that the deposit extends to at least this distance. It may be objected that the trenches shown in figure 29 are much too long, considering the width of the ore-band. It must be noticed, therefore, that both slopes of the ridge would probably be covered with talus-ore and these trenches would therefore indicate the quality and quantity of such ore available, and, moreover, reveal any subsidiary ore-bands, should such exist, as is not infrequently the case. It may happen that the outcrop takes the form of a more or less horizontal capping on the top of a hill, with the ore not extending down the sides. A trench or trial pit carried to a depth of 20 to 50 feet—or an adit driven into the edge of the capping some 30 feet below the top—will then probably show a passage down into rock that is too poor in manganese-ore to be workable; and in such a case, as is so common in Mysore, it will probably be useless to look for ore on the low ground surrounding the hill, or on its sides, except in the form of detritus derived from the ore *in situ* on the top. This case is illustrated in figure 35.

The Way to Work a Deposit.

It is not to be supposed that the information gained in the way described above, valuable though it be, is necessarily all that is required before work can be started on rational lines. If it has revealed the existence of large bodies of ore near the surface, then there can be no doubt that the deposit should be opened up as a quarry. If the prospecting has revealed the fact that the deposits are of a superficial character, as in the case illustrated in figure 35, there is then also no doubt that the deposit is a quarrying proposition. But supposing that the operations have shown the presence of a band of ore of good quality, but of

small width, say only 5 feet thick. Such a deposit could of course be opened up as a quarry. But it would be much better to ascertain if the deposit extend to any depth, either by a small prospecting shaft, calculated to strike the ore-band at 100 feet, by a small incline shaft on the ore, or by means of boreholes calculated to strike the deposit at depths up to 300 feet. For it would not be economically possible to follow such a thin band to a great depth by quarrying, on account of the enormous expense of the earthwork that would have to be done; and if mining were necessary it might be better to start straight away on it. This case is illustrated in figure 33, which might well be taken to represent the Gowári Warhona deposit in the Chhindwára district. There must also be many deposits of characters intermediate between the large bodies of ore referred to above, and the thin band found at Gowári Warhona. Hence it is evident that in many cases it would be advisable to wait before opening up the deposit as a quarry, until it has been ascertained whether the ore go to any considerable depth or not, and then to decide if it would not be better to mine the deposit, instead of quarrying it. I suppose, however, it is useless to mention this point, because the owner of a manganese-ore deposit always wants money returns with the greatest possible speed, and can never wait to have the deposit properly developed. However, by following the ore on an inclined shaft it is possible to prove the ore and win ore at the same time.

Having determined the character of the deposit, at least to the extent of finding out something about its width, strike, and dip, and whether any considerable amount of ore be available, the operator can think about opening it up.

Four mistakes to be avoided.

If quarrying be decided upon then there are four main points to be observed if the deposit is to be properly worked. These are:—

1. The waste must not be dumped on the line of strike of the deposit.

2. The waste must not be dumped too near the sides of the deposit, assuming it to be longer in one direction than in the other; and by preference the waste should be dumped on the side away from which the ore is dipping and not on the dip side. The distance to which the waste should be carried depends on the angle of dip of the deposit, and on the depth to which it is likely to be worth while to follow it by opencast work. The flatter the dip, the wider will the quarry have to be for the ore to be extracted down to a given depth, say 100 feet; and the

deeper to which it is worth while to follow the deposit, the wider will be the workings necessary for opencast work.

3. The work of extracting the ore must be accompanied by a suitable amount of *deadwork*, *i.e.*, extraction of the 'country' or wall-rock on either side of the deposit. Otherwise the workings will tend to take the shape of an ever-narrowing groove, from which it will be increasingly difficult and dangerous to extract the ore.

4. Care should be taken when constructing buildings or tramways not to put them in places from which it may afterwards be necessary to remove them; such as on top of an extension of the ore-body, or where they interfere with the proper working of the deposit.

The above remarks may seem to be trite. But all the principles there mentioned have been broken again and again in the course of Indian manganese mining, usually through ignorance of the structure of the deposit being worked, and an eager attempt to obtain as much ore as possible without any regard for the future; but sometimes, in cases where a qualified man is employed, because the management of the syndicate or company will not provide the funds required for the rational development of the deposit.

I now take a few typical cases and give roughly what seems to me the best method of opening up and working the deposit in each.

Thick ore-band of moderate dip forming a hill.

Figures 30 and 31 can be taken to represent cases found fairly often in the Central Provinces, in which a bed-like ore-body gives rise to a small hill, of which it forms the backbone. We can suppose that in each case the ore-body has been shown by the preliminary cross trenches,

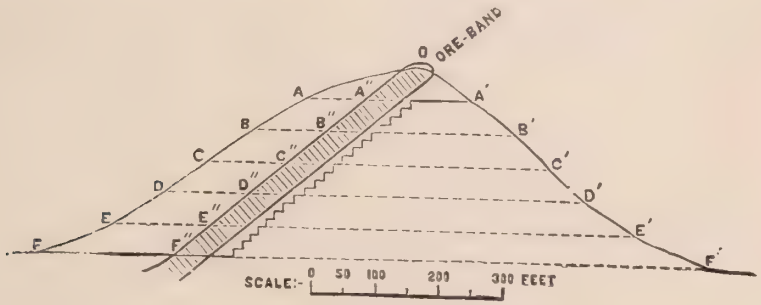

Fig 30.—Quarrying a thick ore-band of moderate dip in a hill.

constructed as illustrated in figure 29, to be of considerable thickness, say 50 feet. In figure 30 it is shown dipping at an angle of 40°, and in figure 31 at an angle of 80°, the slope of the hill on the dip side of the deposit being in each case about 30°. We can also suppose that the hill is in each case about 300 feet high as referred to the low ground at the base. The difference in the dip of the deposits may produce a radical difference between the methods of work to be adopted in each case. In the case illustrated in figure 30, there is little doubt that the deposit should be quarried, at least down to the level of the low ground. This quarrying could probably be most systematically carried out by working the deposit in horizontal slices of a convenient thickness, say 50 feet—AA′, BB′, CC′, etc., in figure 30. Work should be started at the summit of the hill with the removal of the overburden AA″O along the whole length of the ore-body down to the level of the bottom of the first 50-foot slice, AA′. On AA″ a level or bench should then be constructed parallel to the whole length of the ore-band, and tram lines laid down. To remove the ore to the bottom of the hill on the dip side, gravity inclines (tramways) or aërial ropeways, one or more according to the length of level A, should be constructed, with the loading station just below level A, so that the ore in the trucks on this level could be tipped direct into the trucks or buckets of the incline or ropeway. With the slope of the hill given, inclines would probably be better than ropeways; an incline also has the advantage of a greater carrying capacity than a ropeway. From level A the waste should be run out on to the scarp side, OF′, of the deposit, through openings made by deepening the original prospecting cross-trenches down to the 50-foot level AA′. It would be advisable to start work on the outcrop, O, before the level A and the incline are finished, so as to have a supply of ore ready to despatch to the bottom of the hill at the earliest possible moment. With the level A constructed and the dip slope OA″ of the ore-band exposed, it would be an easy thing to remove the ore down to the level A and transport it expeditiously to the foot of the hill. It would probably be advisable to remove the country on the footwall side also of the deposit down to the 50-foot level. It would be as well to arrange to work away the first slice of ore sooner at one end of the deposit than at the other, so as to allow the removal of the country AA″ B″B and the preparation of level B at this end before the ore had been completely removed from the other end of level A. Arrangements would have to be made for moving the loading stations of the inclines down slice by slice as the work progressed. In this way work would be

carried down slice by slice as long as the work of removing the 'country' on the hanging-wall side of the deposit did not become too expensive. This would depend on the relation between the slope of the hill and the dip of the deposit as the base of the hill was reached. It might be necessary in case the slope of the hill became very small to extract the last slice or two by means of a trough-like quarry, instead of removing all the 'country' on the hanging-wall side at this level. As regards the 'country' on the foot-wall side, this would probably have to be removed only for a few feet back from the foot-wall of the deposit, in a stepped fashion as illustrated, the stepping being for safety's sake, except in the case of very sound 'country'. As regards the disposal of the waste, it would probably be too expensive to send it to the scarp side of the deposit, after the first two slices had been worked, unless there happened to be a neck somewhere along the ridge through which a level for the waste could be run. Further, those portions of the waste derived from the workings towards the ends of the ridge could be run round these ends to the scarp side. But the waste from the middle portions of the ridge would probably have to be taken down the inclines on to the low ground on the dip side of the deposit. The above is given as a method suitable for a big thick deposit. The Bálághát deposit is an example of a deposit that is being worked after this method, with the modifications necessary to adapt it to the configuration of the ground. In the case of smaller deposits suitable modifications would be introduced; but the general plan should be based on the above.

Thick ore-band of steep dip forming a hill.

In figure 31 we have a case similar to the above, except that the deposit dips at a much steeper angle (80°) than that of the hill (30°). This should also be worked in slices; but owing to the expense of removing the much increased amount of 'country' on the hanging-wall side of the

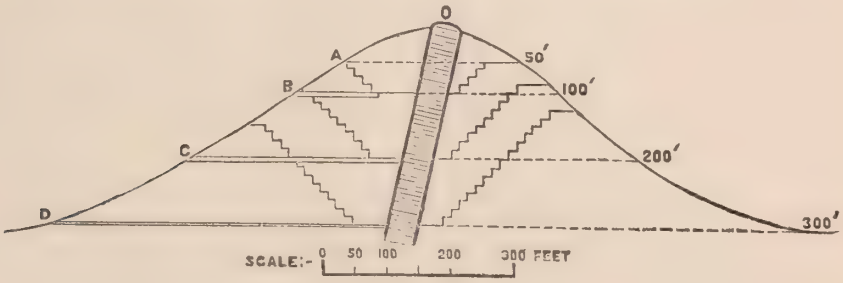

Fig. 31.—Miningor quarrying a thick ore-band of steep dip in a hill.

deposit, it would probably not pay to remove more than one or two 50-foot slices in the way illustrated in figure 30. If the 'country' were very sound and tough, it would probably be cheapest to remove the top 100 feet of the ore by means of an open quarry, as indicated in figure 31, but less wide, and then to drive in tunnels along the strike of the ore-band at the 200-foot and 300-foot levels respectively, and to first stope out the ore from the 200-foot level up to the 100-foot level, removing the ore through the 200-foot tunnel, and to treat the next slice in the same way, removing it through the 300-foot tunnel. [During 1907 a beginning has been made to mine in this way the portions of the Mansar deposit lying below the 100-foot level.] These tunnels would also serve for drainage. In the exceptional case of the ore-band not running the whole length of the hill so that it did not crop out at the two ends, it might be cheaper to drive the cross-cut tunnels B, C, and D, as in figure 31, instead of tunnels on the strike. If, however, the ground were very soft and decomposed it might be easier to continue the quarrying system as indicated by the stepped lines, representing successive stages, down to the base of the hill. Arrangements would have to be made for draining the quarry, probably through the two ends of the ridge. In fact the free drainage of the deposit could to a certain extent be secured by working the ends of the ridge quicker than the middle and so keeping them at a lower level. But whether the ore down to the base of the hill were quarried or mined there is no doubt that mining would have to be resorted to, in order to follow it any deeper, should it continue.

Thin ore-band in a hill.

It is, of course, only if the ore-band were fairly thick that it could pay to quarry the deposit by removing the whole six slices as in figure 30, or by making a wide quarry, as in figure 31. If the ore-band were thin, say only 5 to 10 feet thick, then it would probably be found that the only economical way of recovering all except the top 50 feet would be by mining the deposit like a mineral vein, as indicated in the previous paragraph for the case of a steeply dipping band of considerable thickness, with sound 'country'.

Thick ore-band cropping out on low ground.

We now come to the case illustrated in figure 32 of a fairly thick ore-band, the outcrop of which is on low ground. In this case it does not make much difference whether the angle of dip of the deposit is moderate, as represented in the figure, or whether it is steep, say from 70° to

90° (vertical). In either case it would probably be better to open up the

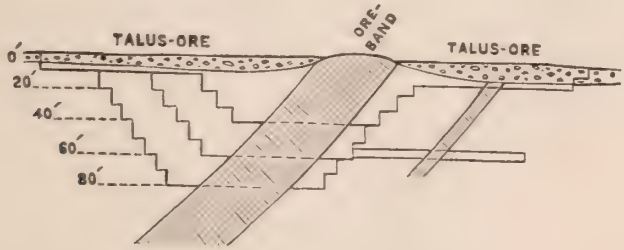

Fig. 32.—Quarrying a thick ore-band cropping out on low ground.

deposit as a quarry, with stepped sides as indicated in the figure, the stepped lines indicating the approximate positions of the sides of the quarries for different depths. The difference introduced by the different angles of dip is that with a shallow dip more ore can be won down to a given depth than with a steep dip, the most favourable condition as regards dip being the one in which the ore-band is folded so as to be kept at the surface for a considerable distance across the strike, as at Kájlidongri (Plate 19). The depth to which such an open quarry could be carried, supposing the ore to continue, depends on a variety of conditions, of which the chief is probably the character of the 'country' or wall-rock of the deposit. It might conceivably be carried to a depth of 150 to 200 feet; but it is probable that before this, except under exceptional circumstances, such as great thickness of the ore-band, accompanied by very high quality, it would pay better to start mining the deposit, by the ordinary methods applicable to veins. It will be seen that if worked as illustrated in figure 30 in the case of a hill deposit, or as in figure 32 in the case of a plains deposit, the side of the quarry on the foot-wall side would keep moderately close to the foot-wall side of the deposit. In these cases it would be as well to drive one or two tunnels into the foot-wall side in order to ascertain whether a second ore-band be present, as might easily be the case, and as is illustrated in figure 32. Or of course the same could be tested by boring.

Thin ore-band cropping out on low ground.

In the case illustrated in figure 33, in which the ore-band is supposed to be only 6 feet thick, and to crop out on low ground, there is little doubt that if the deposit continue to any considerable depth, and it be

desired to win the ore down to this depth, the deposit should be treated

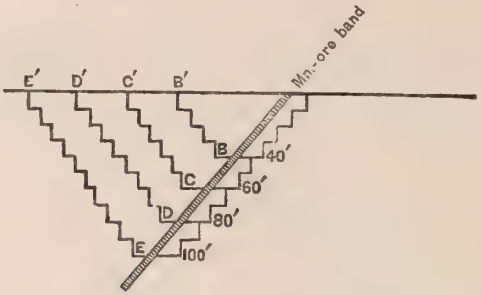

Fig. 33.—A thin ore-band cropping out on low ground.

like a mineral vein from the beginning, and worked by inclined shafts following the dip of the ore, and stoped right out. The deposit at Gowári Warhona in the Chhindwára district, Central Provinces, is a case in point. The dip of the deposit is about 50° as seen in nála sections, and its width is 5½ to 6 feet. The depth to which the ore extends is as usual unknown; the proper way to treat this deposit would be first to bore it and see to what depth workable ore extends. It might only be tested to depths of 150 to 200 feet at first. Then, if the ore were found to extend to only 50 feet or a little more, calculation might show that it would be cheaper to quarry the deposit. But if the ore were proved to continue to 100 feet or more, then calculations would probably show it to be a case of either mining the deposit or leaving it alone altogether. It would not be a fair thing to extract what could be won by opencast work and abandon the remainder. The deposit should therefore either be mined, or let alone altogether until such time as an improvement of communications or prices allow the deposit to be mined. From figure 33 it can be seen how expensive it would be to quarry down to a depth of 100 feet. To win the ore DE between the 80-foot and 100-foot levels, it would be necessary to remove all the 'country' EE′ D′D; and the deeper the quarry became, the larger would be the amount of dead work necessary to win each 26 feet of ore measured on the dip.

Scattered ore-bodies in lithomarges.

We can now consider the case represented in figure 34, which may be taken as a generalized expression of the conditions obtaining in some of the Vizagapatam deposits, although in these deposits there is usually some sign of arrangement of the manganese-ore bodies parallel to

the boundaries of the rock in which they are situated. Let us suppose that workable ores continue to a depth of 300 feet as indicated and that they are scattered through soft lithomargic rocks. The original outcrop is shown at O. The ore-body of which this is part has been worked by

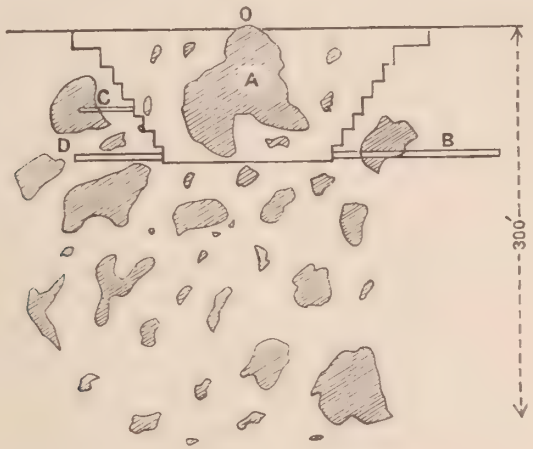

Fig. 34.—Scattered ore-bodies in lithomarge.

means of a large quarry, and found to terminate at a depth of about 100 feet. In quarrying this large mass, however, several small concretions and pockets of ore have been found scattered through the surrounding soft lithomarges. Now it is obvious that if the quarry be abandoned with the idea that the ore has come to an end a great mistake will be made, several times as much ore as that extracted being left in the ground. The obvious point is that the subsidiary concretions and pockets should be taken as a warning, and the surrounding rock explored. Mr. T. Caplen tells me that at Kodur he has found putting down small bore-holes with a percussion drill a very successful method of proving the existence of scattered bodies of ore. Tunnels driven horizontally from the sides of such a quarry would also be of great value, as illustrated by B, C, and D, in the figure, two of them striking ore and one missing it. Having proved the existence of these scattered ore-bodies to a depth of 300 feet, it is a very difficult question to settle how to win this ore, considering the softness of the rocks in which it lies. It is obvious that to make sure of missing no body of any size it would be necessary either to remove the whole of the rock from

the ore-bearing area, forming an enormous quarry of great depth, or to mine the lower portions of the deposit, driving a large number of bore holes to find where the ore-bodies lie. Such a process of mining would need very expensive timbering on account of the softness of the ground, and would be very uncertain, with the probability of leaving undiscovered in the ground a considerable proportion of the ore. A similar problem has arisen at Crimora in Virginia, where the manganese-ore occurs as concretionary nodules and pockets scattered through clays occupying a basin over 200 feet deep. This occurrence has been tackled at different times by means of shafts and open pits; the former method was found to be so uncertain that it has been lately decided to hydraulick the whole deposit, as described on page 575. The Vizagapatam deposits are not however suitable for this treatment, in the first case because it would rarely be possible to find lower ground close at hand on to which the water from the hydraulicking could run, and secondly because the proportion of small concretions in the lithomarge is small compared to the more massive ore-bodies, which are usually of much too large a size to be amenable to such treatment. It might be possible in rare cases to treat Indian deposits by hydraulicking, but I cannot point to any good example. Hence it is an alternative between mining such deposits as Kodur below the 100-foot level, this being uncertain as to finding all the ore, very expensive on account of timbering, and not improbably dangerous; and continuing the quarrying to depths greater than 100 feet (a depth already reached at Kodur). It will probably be found necessary to continue the open quarry system to still greater depths than have at present been reached and then either to abandon the deposit or attempt to win as much as possible of the remaining ore by underground mining, at times when the market is high.

Lateritoid cappings.

The next case to be considered is that illustrated in figure 35. It represents a capping of mixed manganese- and iron-ores of lateritoid aspect,[1] such as is often found in Mysore. These deposits do not continue to any depth, for they have been formed by the superficial replacement of quartzites and phyllites and pass irregularly down into these rocks through a zone of decomposed and partly replaced rock. The thickness (*i.e.*, depth) of the deposits is

[1] For the meaning of this word see page 382.

in all probability rarely greater than 30 to 50 feet, and hence the problem

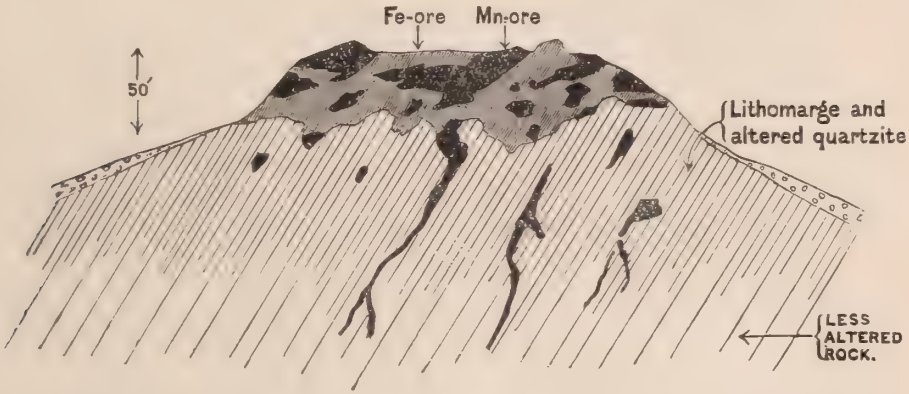

Fig. 35.—A lateritoid capping.

of working them is a simple one. It consists in removing the whole cap of the hill wherever it shows a sufficient proportion of manganese-ore. The waste can be thrown down the slopes in any direction, once the loose deposits of detrital ore, derived by denudation from the cap and lying on the slopes, have been worked over. When the underlying soft rocks have been reached, it is hopeless to expect any continuation of the deposit at greater depths, except perhaps for a few isolated pockets scattered through the soft lithomarges (or decomposed quartzites), the form usually taken by the decomposed rock immediately underlying the manganese-ore of the cap. The point then to be settled by the operator is whether it is worth his while to turn over this soft lithomarge in search of isolated pockets, or whether it is better to leave such pockets in the ground. To do the latter would not be a matter of much concern to the Government; for the quantity of ore so lost would be small; but it is probable that at times of high prices it might pay to work over these soft lithomarges in cases where the indications look favourable.

Deposits of detrital ore or talus-ore.

The last type of deposit to be considered is that illustrated in figure 36, namely the deposits of detrital ore, to which I have usually referred in this Memoir as *detrital ore* or *talus-ore* but which is usually termed *boulder-ore* or *float-ore* by the mining community. These detrital deposits are formed by the denudation of deposits *in situ* and are usually to be found on the slopes and at the foot of hills showing an outcrop of manganese-ore, being as a rule best on the scarp side. In the case, also,

of deposits that crop out on low ground there is usually a covering of

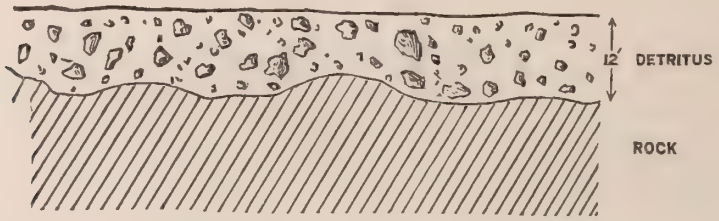

Fig. 36.—A detrital or talus-ore deposit.

detrital ore a few feet thick. In many cases these detrital deposits have to be worked in the course of opening up the ore-body *in situ*. But this is not always the case. Thus, in the case shown in figure 30 on page 555, there would in all probability be a considerable quantity of detrital ore on the scarp slope OF′. Before throwing down this slope the waste from uncovering the ore-body *in situ*, all the detrital ore should be worked over. This is not a counsel of perfection; for it often happens that considerable quantities of good merchantable ore may be quickly won at a small cost from the detrital deposits; and the income derived from such may be a great help to the hard-pressed manager by allowing him to give his company an immediate output of ore, and leaving him some time to open up the deposit *in situ* in a rational way. It is also worth noticing that some *in situ* deposits, namely those formed at the surface, show a progressive deterioration with depth, the best ore being that immediately at the surface. From this it follows that in many cases the ore found in the detrital deposits, having been formed by the denudation of the uppermost portions of the ore-body *in situ*, must be of a better quality than that found in the latter. Even in working over detrital deposits, in which the ore fragments occur in variable abundance, and usually in a matrix of clayey, loamy or gritty soil, it is well to employ some system. I had the difference well illustrated at the deposits situated near Shiddarhalli, in the Shimoga district. In both cases I am referring to detrital deposits consisting of loose fragments of ore scattered through a clayey or loamy soil to depths up to 10 feet or a little more, and lying on comparatively level ground at the base of hills from which the ore had probably been derived. In the one case the deposits—those situated in the Kadur district, Hádikere village limits, just over the Shimoga boundary, and east of Shiddarhalli—had been worked anyhow. Pits had been dug here and there and the waste from the extraction

of the ore dumped immediately by the side of the pit, usually on ore-bearing ground not yet turned over, and the whole then abandoned, though it may be but temporarily. To win the ore now covered up will cost more than if the waste had been carried to a safe distance; and in some cases the cost of removing this overburden will doubtless be considered too great to permit of the working of the ground underneath. In the other case, in a deposit lying to the south-west of Bálekatte and north of Shiddarhalli village, the ground had been divided into strips 5 or 6 feet wide as illustrated in figure 37. Alternate strips A were being worked. The method adopted was to excavate the C end of the strip to as great a depth as was considered payable—some 5 or 6 feet in this case—and remove the waste from this to a safe distance. The remainder of the strip was worked over by men advancing from C towards A and pulling down with kodalis, into the cavity already made, the ground in front of them. In this way they worked along the whole strip, extracting the loose pieces of ore as they turned them

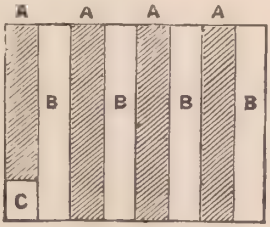

Fig. 37.—Systematic plan of working detrital deposits.

up, and raking the loose soil behind them, women being employed to remove a certain proportion of this soil so as to keep the trench sufficiently open. When the A strips had been worked over, then the B strips were to be treated in the same way. The reason for working alternate strips was probably the convenient disposal of the ore won, and the convenient access of the coolie women who removed the ore and waste. It struck me that this was the best and most systematic method I had yet noticed of working detrital deposits. It must be observed that in this case the only object was to win the loose fragments of ore, for there was no reason for supposing that the detritus overlay manganese-ore *in situ*. In the latter case, it would have been necessary to remove all the soil to a distance. These detrital deposits, when of large extent, would seem to be admirably suited for treatment on the lines of the Northamptonshire iron-ore deposits, *i.e.*, by working

with a long working face and tramlines that are moved forward every time a slice of ore of given width has been removed from the whole length of the face.

In the foregoing paragraphs I have attempted to indicate roughly the methods that seem to me to be most applicable to the working of the various types of manganese-ore deposit. There are many departures from the above types, and each departure introduces a modification in the precise method of tackling the deposit.

CHAPTER XXVII.

ECONOMICS & MINING—*continued.*

The Mining or Quarrying of Manganese-ores—*contd.*

The methods actually used in working the Indian manganese-ore deposits—Indian manganese quarries legally mines—Classification of deposits—Brief description of method of working Indian deposits—Gravity-inclines and ropeways—Mining tram ways and railways—Sampling—Deposits often badly worked—Waste of smalls and dust—Waste of low grade and siliceous lump ores—Possibility of washing, concentrating, and briquetting, smalls and fines.

Methods of mining, concentrating, and briquetting manganese-ores used abroad—Briquetting in Brazil—Hydraulicking and washing in Virginia—Mining, washing, etc., in Panama—Mining of manganese deposits in other parts of the world.

The grant of mineral concessions in India.

The Methods Actually Used in Working the Indian Manganese-ore Deposits.

We can now consider the methods actually employed for the extraction of the Indian manganese-ores. In the first place it must be remarked that owing to the occurrence of large bodies of ore at the surface, the ore of which can be won with little trouble, practically all Indian manganese extraction comes under the head of quarrying. In rare instances, such as at Kodur, Rámandrug, and Bikonhalli, small tunnels have been driven into the quarryside or hillside, in order to extract ore, or test the extension of the deposit below the level at which work was actually being carried on. Such tunnels can be put under the head of mining; but this is all that can be so described. There is of course no doubt that in India the conditions—chiefly the presence of large quantities of high-grade ore at or close to the surface, and the cheapness of the labour—greatly favour quarrying as compared with mining. But, there is also little doubt that considerable portions of the ore-bodies in some parts of India lie at such depths below the surface that they can be worked only by true mining methods. And to me it seems there is little doubt that in years to come, after the more-easily-won portions of the deposits lying near the surface have been removed, it will be found necessary to resort to mining And with a view to this some of the manganese companies and syndicates will probably find it desirable to test the extension of their deposits, below the depths at which they are at present working, by means of bore-holes,

and of tunnels into hillsides, in the case of deposits forming comparatively high hills.

Indian manganese quarries legally mines.

It is interesting to note here that although practically all the manganese workings in India can be most accurately described as 'quarries', yet according to the Indian Mines Act, 1901, clause 3 (*d*), the term 'mine' applies to all workings made for commencing or opening any mine;

'but it does not include any pit, quarry or other excavation the depth of no part of which, measured from the level of the adjacent ground, exceeds twenty feet and no part of which extends beneath the superjacent ground'.[1]

Hence all manganese workings deeper than 20 feet are legally mines, and as such subject to the operation of the Indian Mines Act, 1901. Hence, except in this chapter, I have not been strict in the use of the term 'mine' as applied to the Indian manganese workings, and have often used it in lieu of the more correct term 'quarry'.

Classification of deposits.

From the point of view of the extraction of ore the Indian manganese-ore deposits may be divided into two main groups, each with two sub-divisions, as follows:—

A. Those occurring on hills, ranging in height usually from 50 to 500 feet; divided into:—

(*a*) Those that form a sort of backbone to the hills, often extending down to and below plain level.

(*b*) Those that form cappings to the hills.

B. Those lying on low ground so that their highest points are, or were before being worked, either just a few feet above the level of the low ground, just on a level with it, or even a little below, the presence of the deposit in the last case being indicated as a rule by the presence of detrital ore on the surface; divided into:—

(*a*) Those extending to some considerable depth below the surface, either in the form of a sheet-like mass or bed, or in the form of an irregular mass or masses.

(*b*) Those of purely superficial character, that do not as a rule extend to greater depths than 20 or 30 feet.

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[1] W. H. Pickering and W. Graham, 'The Indian Mines Act, 1901', p. 12 (1907), Calcutta. S. K. Lahiri and Co., Calcutta.

As examples of the foregoing divisions the following may be mentioned :—

A. (*a*. The Kájlidongri deposit, Jhábua State : many of those of the Central Provinces, such as Kándri, Mansar, Bálághát, Mánegaon.

A. (*b*) Nearly all the deposits of the Sandur Hills and Mysore, and most lateritic deposits.

B. (*a*) Many of the deposits of the Central Provinces, such as Kodegáon and Waregáon : a large number of those of Vizagapatam, such as Kodur and Perapi.

B. (*b*) Several of those of Mysore, such as those near Kárekurchi, in the Tumkur district.

There are of course many deposits that do not fit conveniently into this classification. Thus Kumsi in the Shimoga district, Mysore, occurs on the slope of a hill. It can be put into A. (*b*), however.

The chief difference caused by the situation of the deposit is that when working on a hill drainage troubles are avoided, if the work is done rationally, whilst the labour of transporting the ore to the stacking ground can be greatly facilitated by the erection of aërial ropeways and inclined planes, gravity being the motive power : see Kándri (Plate 28), Mansar (Plate 33), and Bálághát. In this way large quantities of ore often can be won for many years from the hill deposits before quarrying down to the level of the surrounding plains. On the other hand, in the case of a quarry commenced at the level of the plains, as soon as a depth of 20 to 40 feet is reached, water troubles usually begin, so that extensive pumping is required, as at Kodur (Plate 47) and Garbhám in the Vizagapatam district, and Beldongri and Kácharwáhi in the Central Provinces (Plate 41). Eventually a depth is reached at which it becomes a matter of great difficulty to quarry the ore, and it is then that proper mining operations become necessary if the deposit is not to be abandoned, as was done in the case of the Waregáon deposit, in the Nágpur district. But in the case of such a deposit as Waregáon, which is imagined to have given out at the same time as water troubles prevented further work, there seems to be no desire on the part of the miners to ascertain to what depth the ore continues, and determine whether it would be worth while to try and win the remainder of the deposit by mining it.

The chief difference between the working of the deposits of groups A.(*a*) and A.(*b*) is that in the latter case the problem is simply one of removing a

capping of some 50 feet in thickness, or less, and separating the ore from the rock with which it is so often associated and intimately mixed, this admixture being due to the fact that these cappings are usually the result of the superficial, and often very irregular, replacement of some practically non-manganiferous rock: whilst in the case of A. (*a*) provision has to be made for the probability that the ore-body extends into the hill as a sort of backbone, by carrying out a sufficient amount of deadwork to prevent the quarry becoming an ever-narrowing groove.

The chief difference between the workings of the deposits of groups B. (*a*) and B. (*b*) lies in the fact that the deposits of group B. (*b*) do not extend to any depth; so that it is not necessary to make the provision in the way of deadwork that is necessary in the case of the deposits of group B. (*a*) to prevent them becoming ever-narrowing grooves or pits.

Brief description of methods of working Indian manganese-ore deposits.

Whatever may be the situation of the deposit, a large proportion of the work is done by hand. When in very hard, compact masses the ore is first hand-drilled, two men usually working at each drill (see Plate 30), and then blasted. Otherwise it is simply prized out with crowbars, advantage being taken of the divisional planes of the ore-body when such are present. The huge blocks thus detached are broken with heavy sledge-hammers to a manageable size and then, though with many exceptions, carried down the hill, or up out of the quarry, as the case may be, on the heads of women and children. At a number of quarries light rails have been put down to facilitate the disposal of both manganese-ore and waste. The ore is, if necessary, cleaned by women, children, and old men, with small cobbing-hammers, and finally piled into rectangular stacks ready for measurement. Where a chemist is employed the stacks are usually sampled (Plate 36), and assayed separately, and the ore then carted or trammed to the railway station, where the products of different quarries are often mixed or blended so as to yield a cargo of a certain standard (Plate 41).

Gravity-inclines and aërial ropeways.

The foregoing represents the most general practice, to which there are of course, many variations. As already mentioned the carriage of ore from the summits of hills to the foot has been in several cases facilitated by the construction of gravity-inclines (gravity tramways) and aërial ropeways. Gravity-inclines have been constructed at Kándri, Mansar, and Bálághát, all worked by the Central Provinces Prospecting Syndicate, and at Rámandrug, worked by the General Sandur Mining

Company, Limited. Aërial ropeways have been erected at Kándri, Mansar, and Rámandrug. Of these the Mansar ropeway has been dismantled and replaced by a gravity-incline. The Rámandrug one has a length of about 2,400 feet with seven supporting trestles, and lowers the ore about 750 feet. The details as to these ropeways and inclines will be found under the headings of the respective deposits. Occasionally ore-shoots have been constructed to facilitate the lowering of ore from one level to another, as at Mánegaon, worked by the Central India Mining Company, Limited. The rails used on the mines are usually of 2-foot gauge, but are occasionally of 2′ 6″ gauge, as on the mines of the Central Provinces Prospecting Syndicate. In several cases light steam tramways or light railways have been constructed to connect up various mines to the railway systems of the country. An account of these is given on page 477.

Mining tramways and railways.

On the 2-foot gauge lines laid down by the mining companies, the trollies or trucks usually used hold from one to two tons, according to the size of truck. The New Mysore Manganese Company, however, is using some trucks that hold up to three tons of ore. On the 2′ 6″ and metre-gauge lines constructed by the railway companies, wagons holding 6 to 16 tons are used.

Samples for analysis are not always taken from ore stacked at the mine as mentioned on page 570; at some mines the ore is never stacked. Thus, at Bálághát, the ore receives what cleaning it needs near the working face and is then charged into mine trollies and conveyed by a series of tramways and inclines to the railway wagons. The ore is sampled by taking some ore out of each mine trolly as it passes the manager's bungalow. At Kumsi the ore is railed part of the way and carted the remainder. The chemist takes his samples from the carts on arrival at Shimoga[1].

Sampling.

I do not propose to give here descriptions of how particular deposits are worked. For this I will refer the reader to the fourth part of this Memoir. There he will find, at the end of the description of each deposit, an account of the way in which it was being worked at the time of my visit. The description given on page 570 applies to most of the deposits. But in a few cases the work has been carried out on more elaborate lines; for this attention may be directed to the descriptions of the way in which

[1] For some remarks on sampling Indian manganese-ores see *Trans. Min. Geol. Inst. Ind.*, II, pp. 95—98.

the Kándri, Mansar, and Bálághát deposits, are being worked, these being the best examples of deposits well worked.

Deposits often badly worked.

It will have been gleaned, however, from the earlier portions of this chapter, that many of the Indian manganese-ore deposits have been very badly worked. In my paper 'Manganese in India', p. 107, I wrote:—

'ore has often been recklessly extracted to meet present demands and contracts without any regard either to geological considerations or the future working of the deposit. This has frequently resulted in the subsequent discovery, either that the waste or *mati* has been dumped on to the hidden extension of the ore-body, or that so much dead-work will be necessary before the miner can work at a slightly increased depth, that it becomes a matter of doubt if the deposit can any longer be profitably exploited; such want of foresight and reckless working leads, of course, to a grievous waste of the country's mineral resources.'

Since this was written I have been able to revisit some of the deposits in the Central Provinces. I was pleased to find a general improvement in the methods of work, although there were still some deposits left to which the foregoing was applicable. I have also since visited some of the Sandur deposits, and some of those of Mysore. The Sandur deposits were being worked with some care and forethought. So also were some of those of Mysore; but not the majority. The majority were being worked in a very careless fashion; but, considering the fact that these deposits do not extend to any depth, this is not a matter of much consequence. In working loose detrital deposits, however, it must be very difficult to tell which ground has been worked over and which not, if the waste is dumped immediately by the side of an excavation and on top of ground not worked over, as noticed on page 565. I have heard it remarked that working some of the Mysore deposits is like digging for potatoes. The simile was meant to apply to the irregular distribution of the ore in the lateritoid masses. But it is more aptly applied to the deposits of detrital ore, where fragments, pebbles, and boulders of ore lie scattered through a clayey soil; except that in some cases the workings are much less regular than digging for potatoes would be if the digger did not wish to leave a considerable proportion of his potatoes in the ground.

Waste of smalls and dust.

Not only is there in India a strong tendency to work the manganese-ore deposits in a very wasteful way, especially at the beginning of work by a new operator, but there is also a tendency to waste a considerable proportion of the ore won. To begin with, all ore at all small in size, say below one inch in diameter, is in most cases thrown away irrespective of quality,

probably because some mechanical treatment might be necessary to separate these small pieces from small pieces of foreign matter. It is to be noted that the worst offenders in this waste of smalls are those operators who can obtain large quantities of ore in large pieces. Operators with properties that turn out inferior grades of ore only, do often stack these smalls and seem to be able to find a market for them. Further, at many even of the best deposits, a certain proportion of the ore breaks down into powder during excavation. This applies particularly to those deposits in the Central Provinces in which there is any ore consisting entirely or almost entirely of granular braunite, without any psilomelane as cementing material. Kándri is a good example of a deposit in which a lot of the ore breaks down into powder on quarrying. All this is wasted. The same applies to deposits in which there is a considerable proportion of pyrolusite, such as some of those of Vizagapatam, and many of those of Mysore. In some cases pyrolusite has been bagged and sold, as at Kodur in Vizagapatam, and Hoshalli in Mysore. But in the majority of cases this pyrolusitic ore is stacked in such lumps as can be obtained, all that breaks into powder during quarrying being lost. Such ore if exported in the unbagged condition must then inevitably loose greatly in weight owing to powdering at every transhipment or dumping. My opinion is that such soft ore should be bagged at the mine, and that when a large amount of ore breaks down into powder, some attempt should be made to recover this by some means of washing the dust and concentrating it; this applies especially to such a deposit as Kándri, whence there is a large outturn of lump ore bringing in a handsome profit to the operators, so that there can be no lack of the comparatively small capital required to provide the plant that would be needed for the treatment of smalls and dust. It is very pleasing to the miner to export the very best ore and make a sovereign a ton profit on it with a comparatively small amount of trouble, and to neglect all ore that will not bring in profits at the same rate; but it is not gratifying to India, to see a portion of her mineral capital wasted.

Waste of low-grade and siliceous lump-ores.

Similarly, of the ore that is obtained in lump size, only that of the very best quality is considered worth noticing in some quarters in the Central Provinces. It is probably sometimes the case that a firm wishes to get a reputation for supplying ore only of a certain quality, although it could also work lower grade ore at a profit if it liked. To do this such firms throw away all ore of lower grade than their standard,

except what they can blend in with the highest grade ores without the product falling below the standard. But much of such ore as is rejected could probably, with a little trouble in cleaning it, be sold at a profit, at least at times of high prices. It seems moreover to be overlooked in India that much of the ore that is rejected because it is too high in silica, although it is not very much below marketable standards as regards manganese contents, could be worked up into a merchantable product by crushing and concentrating. Each particular case would need investigation to see if such a process could be commercially successful, considering the distance of the markets. But I think that in many cases the treatment of this ore would pay, at least at times of high prices. And in the event of the ore being smelted in this country for the manufacture of ferro-manganese there could be little doubt of the financial possibility of such a project. It is probable, however, that, if the Indian manganese operators have considered any such project, they have rejected it because they can supply all demands from the easily-won lump-ore of high grade, and not because they have seriously determined that it would be financially impossible. In case then the Indian manganese operators are content to make use only of the high-grade lump-ores, I think they should recognize that they are probably throwing away large quantities of material that has a possible value in the present and a more probable value in the future, and that they should make some attempt to stack the lower grade and siliceous ores separately from the waste thrown on the dumps.

Possibility of washing, concentrating, and briquetting, smalls and fines.

Methods of Mining, Washing, Briquetting, etc., used Abroad.

The reasons why I think that washing, and concentrating if necessary the fines, and crushing and concentrating the low-grade ores at present thrown away, and in either case either bagging or briquetting the product, could be made a commercial success, is that it has been done in several cases before in other parts of the world. Thus Mr. H. Kilburn Scott in some notes appended to a letter sent to me in February 1906 refers to the briquetting of manganese-ores in Brazil as follows :—

Briquetting in Brazil.

'The Usina Wigg, the principal mine operator in the Ouro Preto Branch Line deposits, commenced last year the erection of a plant for briquetting the finely divided ore after reducing its moisture contents.

'The installation has been carefully designed, and will have a capacity of 100 tons of briquettes per day. The process has been evolved by Messrs. Zeitz & Co. of Saxony who are supplying the greater part of the machinery. The binding material will be furnished by a proportion of the moisture left in the ore after reducing to the size of 1½ millimetres. The presses will work with a pressure of 10 tons per square inch and the briquettes will weigh 800 grammes each.

'Experimental briquettes have been found to resist shock and high temperature without disintegrating, so much is expected from the process.'

The Brazilian ores are very high in moisture (up to 20%); in briquetting soft Indian ores it might be necessary to add moisture.

Hydraulicking and washing at Crimora in Virginia.

Further in an article in the *Engineering and Mining Journal*, 9th March 1907, p. 478, Mr. E. K. Judd gives an interesting account of the way in which the manganese-ore deposit at Crimora in Virginia is worked by the Crimora Manganese Company, by hydraulicking and washing. In order to show with what elaborateness a manganese-ore deposit may be worked I quote extensively from this article :—

'The Potsdam quartzite, forming the base of the district, has been eroded by some peculiar agency so as to form a bowl, perfectly inclosed on all sides, except, where, at the north, a stream has eroded a narrow gorge. This drains only a small part of the bowl, and the remainder has no natural drainage whatever. The bottom of this bowl has been filled to a depth of 212 ft., at the centre, with a stiff red clay, covered with a layer of gravel drift with an average depth of 15 ft. In this clay, manganese oxides are found in rounded concretions, and irregular pockets, seams and stringers, whose position follows absolutely no apparent rule. They are found at all depths, and in all shapes and sizes, from that of a pea to masses of several tons weight . . . . .

'The manganese-bearing portion of the bowl has been determined, by drill borings, to cover an area of a little over 100 acres.

Method of Mining.

'In the early days, when the ores first attracted the attention of the Carnegie steel interests, the clay was thoroughly honeycombed with shafts and drifts which required timbering of the most substantial nature. The lowest workings of that epoch reached a depth of about 100 ft. below the original surface, when the copious influx of water naturally gravitating to this spot and finding no outlet, forced abandonment of the project. Although the old operators removed the choicest ore-bodies, the inefficiency of their methods is shown by the great quantity of valuable ore that is now recovered, by open working, from the close neighbourhood of the old openings, and even in among the very timbers of the disused drifts.

'The present system of mining may have been suggested by that so successfully practised among the largest gold gravel operators of the Sierras, but it is probably unique among manganese miners. The first step was to drive a drainage tunnel 5,800 ft. long through the quartzite rim, tapping the bottom of the basin at its lowest point, and discharging into one of the small streams that flow into the south fork of the Shenandoah. A shaft 202 ft. deep then connected its inner end with

the surface. In the neighbouring mountains, an extensive system of reservoirs and flumes was then constructed, ending in a small masonry tank above the mine, from which a steel pipe, crossing on a trestle the deep gulch above referred to, leads the water to a nozzle in the working place. The tank is now 224 ft. higher than the nozzle, and the discharge is 640 gal. per minute.

'The wash from the clay banks thus attacked is allowed to settle in the bed of the working place, so that only the clay is carried off in the overflow down the drainage shaft. The sand and gravel, together with the big fragments of ore, are then collected in cars travelling on movable tracks, and carried to the washing plant, close to the edge of the pit. The area now under work covers 5½ acres, and a depth of 56 feet below its present level will have to be gained before the untouched ore will become available. The entire output now comes from ground that was overlooked by the earlier workers. An ordinary section of clay bank, in which no especially heavy lumps are encountered, will carry around 10 per cent., by weight, of manganese oxides. Wad, which is rather abundant in some spots, can not be saved in this way, and is lost. In any case it would require calcining to bring it up to shipping grade.

'A steam shovel is used for removing the gravel overburden. Trains of dumping cars are brought around to it, on track laid close to the edge of the pit, loaded, and drawn off to a waste dump at some distance from the mine, at a total cost of about 6c. per cu. yd. Waste from the washery is disposed of in the same way.

Washery Operations.

'The washery has a double-tracked incline extending from its top floor to the bottom of the pit, and carrying a pair of self-dumping skips. The loaded cars from the pit, whose contents still retain a lot of adherent clay, dump into a sump which is kept half full of water, so as to cause the material to flow easily. The mixture is then drawn off through gates into the skips and hoisted to the top of the washery. Here it passes into an inclined double logwasher fed abundantly with water, where most of the clay is washed off and discharged. The lumps then go through a crusher and into another, but horizontal logwasher, where the last clay is removed.

'The discharge from this washer goes into a trommel with ⅝-inch holes; the oversize passes to picking belts where waste is discarded and the ore becomes ready for market. The undersize goes to another trommel, which makes four sizes, and each size falls into a separate jig. The McClannahan jig has proved admirably suited for this work and makes a clean separation into heads and tails, with no middling product. The tails, carrying 3 or 4 per cent. of manganese, are sold to foundries and basic steel makers. The waste from the picking belt sometimes carries as much as 20 per cent. manganese. A great deal of this waste is in the form of quartzite conglomerate, manganese oxide being the cementing agent, and, if crushed again, might yield some good ore; the management, however, is storing this material until it can find a market, it being worth more than jig tailings.

'No attempt is made to reduce the size of the ore, the management preferring to sell its product in lump form to the steel industry..... It is probable that the small additional outlay for grinding equipment would prove a good investment, since the other consuming industries, the glass, the paint, and the storage battery manufacturers, are accustomed to pay about-double the price allowed by the steel makers.

'The lump ore shipped from the mine averages around 48 per cent. metallic manganese, and occasional lumps reach nearly to 60 per cent. Phosphorus rarely

exceeds 0·10 per cent., but silica is rather high, ranging from 2 or 3 up to 15 per cent. The jig concentrates range in silica 2 or 3 per cent. higher than the lump ore produced at the same time.'

Methods of mining, washing, etc., employed in Panama.

As a further example of the trouble that is thought worth while in other parts of the world in working manganese-ore deposits, so as to make use of all possible ore, I give the following abstract from a paper by Mr. E. G. Williams, entitled 'The Manganese Industry of the Department of Panama, Republic of Columbia', *Trans. Amer. Inst. Min. Eng.*, XXXIII, pp. 214, 215 (1902).

'The discovery outcrop is about 100 ft. below the summit of the hill. An open cut was begun about 20 ft. below the outcrop and carried in until the walls were 100 ft. high. The mountain, rising faster than the ore-body, gave a constantly increasing over-burden to remove: and this, with the difficulty of holding the side-walls, led to the abandonment of open-cut work and the beginning of underground mining in 1898. A tunnel was driven into the ore-body from the open-cut level, and from the same level a shaft was sunk 110 ft. and two levels were opened. The mine is drained by a tunnel on the bottom level connecting with the shaft.

'The ore is usually stoped for the entire width of the deposit, both heavy timbering and supplementary filling being required. At some points it is necessary to leave pillars of ore in place, to be extracted when the stope is about to be finally abandoned. The ground is difficult to hold, because of the decomposed rocks surrounding the ore and the large masses of clay associated with it. Occasionally a pocket of clay is opened which is under heavy pressure from the surrounding rock or ore. As soon as an outlet is furnished, the clay begins to flow into the stope in a plastic mass: and great difficulty is often experienced in checking this flow. The most satisfactory method of working—indeed, the only one by which the soft clay walls can be held—is to keep the stopes filled to within about 7 ft. of the roof. The ore-shoots and man-ways are built up from the level below, as the filling is carried up. The material for filling, apart from what is furnished from waste in the mine, is obtained outside, on the open-cut level.

'Square-set timbering has been used in large stopes, but it has been found better and cheaper, where the filling system was employed, to support the roof with cribs of round logs, which accommodate themselves, without damage, to the shrinkage of the newly-filled material and the pressure from the ore.

'The ore from the lower levels is hoisted to the open-cut level by a gasoline hoist, which was installed on account of the difficulty of obtaining a supply of water through the dry season.

'The ore is hand-picked on the open-cut level, the large pieces going direct to the tramway which connects the mine with the railroad, while the small pieces and finely-powdered ore are transported separately, taken to the log-washer, and screened after washing.

'The size above 0·5-in. mesh is hand-picked and shipped: the finer portion being reserved until a suitable concentrating-plant shall have been erected. This care in sorting the ore is rendered necessary by the presence of particles of jasper in the ore, which, if not removed, subject the ore to a penalty for silica.

'The ore is stored on the upper level of a 50-ton bin at the loading terminal of a Bleichert tramway. This tramway, about one-third of a mile in length, has

its upper terminal 420 ft. above the railroad to which it conveys the ore. At the railroad there is a 300-ton ore-bin, from which the railroad cars are loaded. The tramway is operated by gravity, the descending loaded buckets developing 6-H.P. All mine-supplies, timber, etc., are brought up to the mine on the tramway, which has a capacity of 25 tons per hour.

'Hand-drilling was used until the present year, when, on account of the difficulty of obtaining labourers during the revolution in the country, an air-compressor was installed, driven by a 35-H.P. gasoline-engine, and power-drills are now used.'

From this account it will be seen that not only has it been found profitable to work the deposit (the Soledad deposit) by the methods of underground mining, but it has also been thought worth while to wash and screen the smalls, whilst it was intended to set up a concentrating plant for ore passing a $\frac{1}{2}$-inch sieve. It is also interesting to note that power drills have been introduced in place of hand-drilling. The ores shipped from this deposit are of about the same grade as those of Kándri. The methods described have been no doubt largely adopted on account of the scarcity of labour. The same desire to save labour appears in the arrangements for the transport of the ore which are described as follows (*loc. cit.*, p. 219) :—

'From the bins at the railroad the ore is loaded by gravity into small side-dumping cars, of about 3 tons' capacity, and hauled to the shipping-port. Here it is dumped from a trestle upon the stock-pile. There is storage here, without re-handling, for about 3000 tons. The ore is shipped in steamers which are loaded alongside the Company's wharf. It is loaded into tubs, holding about 1800 lbs. each, which rest on small trucks running on a track of 0·5 meter gauge. There are two endless tracks, one on each side of the ore-pile, extending on to the wharf. The ore-trucks make a continuous circuit, the loaded tubs being hoisted and their contents dumped into the steamer's hold, and replaced empty up on the truck which then returns to the ore-pile to reload. Each track serves a separate hatch on the steamer ; and the ore is loaded at the rate of 400 tons or more daily.'

This railroad is of 3 feet gauge, 9 miles in length, and connects up the Soledad and Concepcion mines of the Caribbean Manganese Company, by whom it was built, to the port of Nombre de Dios.

Mining of manganese-ore deposits in other parts of the world.

Amongst other deposits at which true mining methods have been adopted, or at which the ore is subjected to some sort of concentration, or other mechanical treatment, the following may be mentioned :—

1. The *Miguel Burnier* mines, Ouro Preto area, Minas Geraes State, *Brazil*[1]. Steeply-bedded deposit of average width of 2 metres. Levels driven into hill-side at vertical intervals of 30 metres, and ore stoped out. Briquetting of ores.

[1] H. K. Scott, *Jour. Iron Steel Inst.*, No. 1 of 1900, pp. 190–195.

2. *Morro da Mina* deposit, Queluz area, *Brazil* [1]. A vertically dipping deposit of great thickness, the ore being interbanded with clay. Tunnels driven into the hillside at depths up to 147 feet below original outcrop.

3. *Ponupo* deposits, Santiago de Cuba area, *Cuba* [2]. Irregular pockets in clay and associated with jasper and porphyry at the surface. Some of the ores are washed and concentrated.

4. *Las Cabesses* deposits, Ariège, *France* [3]. An irregular carbonate deposit, altered to oxide at the surface, associated with Upper Devonian limestones. In 1894 a depth of 70 metres had been reached, and the deposit was worked by a series of 8 levels. The ore was treated by means of syringing and hand-picking, grizzlies being used to separate the smalls, and trommels to classify them. The ores are finally roasted.

5. *Romanèche*, Saône et Loire, *France* [4]. Veins, up to 8 metres wide, and masses, of psilomelane and pyrolusite, associated with fault-junction between granite and Keuper, Liassic, and Tertiary, sediments. Worked by shafts, levels stopes, etc., and gradually passes into iron-ore (hematite) at depths of 260—330 feet.

6. Island of *San Pietro, Sardinia* [5]. A seam of manganese-oxide ore, averaging 10 inches in thickness, associated with ochres, and interbedded with trachytic rocks. Average manganese percentage only 30%. Worked by galleries and cross-cuts with timbering.

7. *Rhiw* Mines, Caernarvonshire, *North Wales* [6]. The workings are in veins of ore from 4 to 30 feet thick. Ore averages 30 to 36% manganese, iron 7 to 10%, silica 18%, phosphorus $\frac{1}{3}$ to $\frac{1}{2}$%. Worked by adits and shaft; a depth of 110 feet reached.

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[1] M. A. Lisboa. Reprint from *Brazilian Engineering and Mining Review*, III, Nos. 6 & 7. Received 1907.
[2] H. Souder, *Trans. Amer. Inst. Min. Eng.*, XXXV, pp. 309-312, (1904).
[3] C. A. Moreing, *Trans. Inst. Min. Met.*, II, pp. 250–264, (1894).
[4] Fuchs & Launay, 'Gîtes Minéraux', II, pp. 13-16, (1893).
[5] E. Halse, *Trans. North Eng. Inst. Min. Mech. Eng.*, XXXIV, pp. 145–158, (1885).
[6] *Mining Journal*, June 22nd, 1907, p. 828.

Grant of Mineral Concessions in India.

Originally it was my intention to give in this Part of the Memoir an account of the regulations governing the grant of prospecting licenses and mining leases (1) in British India, (2) in Mysore, and (3) in Portuguese India. But unfortunately I have not had the time for this. Still I can indicate here the sources of information available. The regulations for British India are contained in Resolution No. 18—17-2, dated Simla, the 20th May 1899, of the Department of Revenue and Agriculture. Mr. C. E. Low, Director of Industrial Surveys, Central Provinces, has prepared a handbook explanatory of these regulations with regard to their bearing on the Central Provinces. The rules are, however, at present being revised. Mines in British India are worked under the Mines Act, 1901, for which see a small book of this title by Messrs. W. H. Pickering and W. Graham, published in Calcutta, in 1907, by Messrs. S. K. Lahiri & Co. The rules in force in Mysore are contained in 'Notification by the Government of His Highness the Maharaja of Mysore, Geological Department, No. 555-S., dated 2nd March 1904'. These were modified in subsequent Notifications Nos. 2490, 2521, and 2759, dated 1st, 4th, and 13th June, 1906, respectively; these have, I believe, been subsequently cancelled, leaving the Notification of 1904 still in force. The regulations applicable to the Portuguese territory of Goa are contained in 'Boletim Official do Governo General da Estada da India', No. 84, dated October 23rd, 1906. A translation of this has been prepared by Mr. R. A. Becher, His Britannic Majesty's Consul at Goa, and is for sale at the British Consulate at Mormugão.

CHAPTER XXVIII.

ECONOMICS & MINING—*continued.*

The Uses of Manganese.

Uses in metallurgy—List of uses—History of the application of manganese in the iron and steel industry—Spiegeleisen and ferro-manganese—Manufacture of spiegeleisen and ferro-manganese—Manufacture of ferro-manganese in India—Use of spiegeleisen and ferro-manganese—Quantity of manganese required in the manufacture of steel—Phosphorus and silicon in spiegeleisen and ferro-manganese—Use of the Indian phosphoric ores—Use of manganese-ore for de-sulphurizing—Manganese in foundry practice—Manganese-steel—Effects of manganese on iron and steel—Other manganese alloys—Silicon-spiegel—Manganese-bronze—Metallic manganese.

Smelting of manganese-ores by the natives of India—Kheri.

Use of manganese oxide as an oxidizer—For the decolourization of glass—For bleaching powder, bullion smelting, and potassium permanganate.

Use of manganese as a colouring material—For glasses and enamels—For pottery.

Ornamental applications.

It has already been shown how widespread is the element manganese in Nature (see pages 18-20). The following list[1] will give some idea of the numerous uses to which manganese and its compounds have been applied by man :—

TABLE 88.

List of uses of manganese.

I.—Alloys	Ferro-manganese.	Alloys of manganese and iron.
	Spiegel-eisen.	
	Manganese-steel.	
	Silicon-spiegel.	Alloy of manganese, iron, and silicon.
	Manganese-bronze	Alloy of manganese and copper with or without iron.
	Silver-bronze.	Alloy of manganese, aluminium, zinc, and copper.
	Alloys of manganese with aluminium, zinc, tin, lead, magnesium, titanium, gold, etc.	
II.—Oxidizers	Manufacture of chlorine, bromine, and bleaching powder.	
	Decolourizer of glass.	
	Dryer in varnishes and paints.	
	Leclanché's cell.	
	Preparation of oxygen on a small scale.	
	Manufacture of disinfectants (manganates and permanganates).	

[1] Based on that of Penrose, An. Rep. of the Geol. Surv. of Arkansas for 1890, Vol. I. 'Manganese: its Uses, Ores and Deposits', p. 7.

III.—Colouring materials. { Calico-printing and dyeing. / Colouring glass, pottery, tiles and bricks. / Paints { Green. / Violet.

IV.—Various lesser chemical, manufacturing and medical purposes.
V.—Occasionally as a gem when in the form of rhodonite or spessartite.
VI.—Occasionally as a flux in smelting silver-ores.

I do not propose to discuss here each of the applications of manganese mentioned in the preceding table. That will be found already accomplished, as far as they had been discovered up to 1890, in the most interesting fashion in the work of Penrose just quoted. But I shall notice briefly the most important uses, namely in the metallurgy of iron and steel, and a few of the others as applied to India.

Uses in Metallurgy

History of the application of manganese in the iron and steel industry.

In all probability at least 90% of the world's output of manganese-ore is consumed in the manufacture of iron and steel. It will therefore be interesting to trace briefly the history of the use of manganese in the iron and steel industry. Between the years 1799 and 1837 various patents were taken for the use of manganese in metallurgy. In 1830 David Mushet even succeeded in making a low-grade ferro-manganese containing 30% of manganese. Josiah Marshall Heath, however, in 1839, was the first to conduct experiments on a large scale and bring manganese into general use in the iron and steel industry. Heath was a Madras civilian who abandoned the Indian Civil Service to take up the development of the iron industry of Southern India. He attempted to make use of the low-grade iron-ores used by the natives of Porto Novo in the North Arcot district, in the manufacture of *wootz*, a variety of steel produced by cementation in crucibles. According to Penrose[1] on whom this account is based, and for whose book see for the references to the literature of the subject:—

'He not only succeeded in this, but also completely revolutionized the steel industry of England. His original object was to improve both malleable iron and cast steel. In the first case he mixed with the cast or plate-iron, while fused in the puddling furnace, from 1 to 5 per cent of pure oxide of manganese, the sesquioxide being preferred. In the second case he mixed in the crucible, with the materials to be converted to steel, from 1 to 3 per cent of what he called carburet of manganese. The latter consisted of a manganese pig corresponding to white iron pig, and was composed of metallic manganese with a small proportion of carbon.

[1] *Loc. cit.*, p. 13.

It was made by smelting an intimate mixture of oxide of manganese and coal-tar. . . . . By the addition of this material, it was found that the low grade steel made from the Wootz ore could be converted into an excellent product, easily malleable and weldable.'

He later improved his process by moulding the manganese oxide and tar into bricks, drying them by heating in a closed vessel, and using them in their raw state.

'In this form he soon found an extensive demand for this manganese compound among the steel manufacturers, who, after the first trial, realized the great advantage derived from it. Heretofore the best quality of steel in England had been made of high grade and expensive bar-iron from Sweden and Russia, but by the employment of Heath's process it was possible to make an equally good product from a comparatively low grade iron of English manufacture.'

Heath lost the benefit of his researches through neglecting to patent the use of his mixture in the raw state. D. Mushet calculated that the immediate result of Heath's invention was a reduction of £30 to £40 in the price of good steel, with an aggregate saving up to 1855 of £2,000,000.

The Bessemer process for making steel was made public in 1856 and perfected by 1858, the difficulties experienced in the early working of the process, owing to the burning off of all the carbon in the converter, being obviated by the introduction by Robert Mushet in 1856 of a 'triple compound' of iron, manganese, and carbon, an early form of the alloy later called spiegeleisen. This alloy was used in the Bessemer process for adding to the steel the requisite amount of carbon, the manganese performing various offices, then not properly understood. The need for an alloy containing a higher percentage of manganese than that in the spiegeleisen then made (5 to 10% of manganese and sometimes 6 to 7% of carbon) soon arose, and as the results of some experiments carried out by W. Henderson of Glasgow, at the instigation of Bessemer, a ferro-manganese containing 25 to 30% of manganese was produced in 1865. A little previous to this, however, Dr. Prieger of Bonn seems to have already succeeded in making a high-grade ferro-manganese. The process was taken up by the Terre Noire Company of France, and from about this date a greatly increased demand for manganese-ore sprang up (see account of fluctuations of price of manganese-ores given on page 414).

Spiegeleisen and ferro-manganese.

Spiegeleisen is an alloy of iron and manganese containing usually 5 to 27% of manganese and 4 to 5% of carbon. It shows mirror-like reflecting surfaces on fractures, and hence the name, which is the German for mirror-iron.

Ferro-manganese contains 27 to 86% (or sometimes even 90) of manganese and 6 to 7% of carbon. *Standard ferro-manganese* contains 80% manganese. [According to O. Simmersbach[1], on passing above 27% of manganese, the Fe—Mn. alloys loose their magnetic properties and assume different crystalline characters.]

According to Penrose[2] :—

Manufacture of spiegeleisen and ferro-manganese.

'Spiegeleisen was formerly made by using a manganiferous iron ore in a blast-furnace, or by inserting small quantities of manganese in the iron ore charge. When the amount of manganese became large, however, great difficulties were experienced on account of the high temperatures required to smelt the metal and the loss due to the combination of the manganese with the slag. The more manganese contained in the charge the higher the temperature that is required, and a white heat is needed to reduce oxide of manganese alone. Consequently, in the early manufacture of ferro-manganese, the metal was reduced either in graphite crucibles as in Prieger's method in Germany, or in a Siemen's furnace as in the Henderson method in England, which was later improved by the Terre Noire Company of France. These processes were expensive, the loss was considerable, and the product limited. More modern appliances, however, and greater experience in the use of manganese-ores have considerably facilitated the reduction of the metal, and now ferro-manganese is readily made in any properly arranged blast-furnace, with a high temperature and a strong hot blast. Coke is the best fuel, as it admits of a sharper blast and gives a stronger heat, but charcoal can be used, and Wm. P. Blake describes the manufacture of ferro-manganese with that fuel from a highly siliceous ore at Reschitza, in Hungary.[3] The other desirable features in the process besides those mentioned are: a highly basic slag, secured by large charges of lime; an abundance of fuel; and sufficient time. The basic character of the slag causes the saving of a considerable part of the manganese, which with a less basic, or an acid slag, would combine with the latter and be lost. If the slag is too basic, however, other difficulties are met; and even with all precautions, a loss of 4 to sometimes over 15 per cent of manganese, the quantity varying according to the amount of the metal in the product to be obtained, is often sustained in smelting the ores'.

According to O. Simmersbach, in the article already cited, while 100% (of the metal obtained) of coke is required for the reduction of iron, 250% is required for the reduction of manganese. The charge must be calculated so that the oxygen of the earthy bases, lime, magnesia, and alumina, is at least as great as the oxygen of the silica. A certain proportion of barytes or flour-spar is also necessary, according to some authorities. A practical rule for fluxing given by Phillips and Bauerman[4] is to give twice as much lime (in the form of limestone) and ½ as much

1 'Über die Herstellung von Ferromangan', *Berg- und Hüttenmännische Rundschau*, I, pp. 305-308, (1905); abstract in *Trans. Min. & Geol. Inst. Ind.*, I, pp. 133-135, (1906).
2 *Loc. cit.*, p. 11.
3 *Trans. Amer. Inst. Min. Eng.*, IV, p. 217. (1875-1876).
4 'Elements of Metallurgy,' (1891), p. 286.

barytes as there is silica present in the ore and fuel. An actual example of the charge used at Terre Noire is the following :—

Huelva ores, pyrolusite,	9·6 cwts., with	Fe = 2·91%,	Mn = 52·50%
Almeria do. do.	4·0	Fe = 15%,	Mn = 50 %
Tafna do. hematite,	0·4	Fe = 55%	

Total :—14 cwts. ore, containing average of 4% Fe, and 50·28% Mn.

For this are required :—

Limestone	4·4 cwts.
Barytes	1·2 cwts.

Or more conveniently we can say that 1 ton of manganese-ore, averaging 50% Mn and 4% Fe, requires 6·3 cwts. limestone, and 1·7 cwts. barytes. The product was ferro-manganese containing—

Manganese	83·90
Iron	8·83
Carbon & silicon	7·26
	99·99

and the loss of manganese was 25%.

Judging from the amount of limestone used the average silica percentage of the ores used must have been about 8%, assuming none to have been derived from the fuel. Consumption of coke was 54 cwts. per ton of ferro made.

According to T. Turner [1], in smelting spiegeleisen, the charges are calculated for a reduction of 75% of the manganese into the alloy, and with ferro-manganese for a reduction of 80% of the manganese. According to Simmersbach good ferro-manganese slags contain 7 to 10% of manganese, according to the composition of the ferro-manganese, whilst up to 18 to 20% is not uncommonly found in the slag when easily fusible ores are smelted. Besides the loss of manganese that takes place by passage into the slag, there is also a considerable loss through volatilization in the blast-furnace ; this may range up to 17% and over of the original manganese contents. When casting it is necessary to shut off the blast, as otherwise the composition of the metal might be seriously altered both by volatilization and oxidation. Owing to the corrosive action of the manganiferous fumes from the blast-furnace on stonework, it is advisable to pass the furnace gases through a washer or dust-catcher before letting them into the fire-brick stoves. If the ore is highly oxidized, containing a high percentage of MnO_2, the gases derived from the furnace

[1] ' Metallurgy of Iron ', p. 150, (1895).

have a low heating power owing to the surplus oxygen burning CO to CO_2. In this case it may be necessary either to add bituminous coal to the charge to furnish gas for the boilers and stoves, or to calcine the ore beforehand to reduce the MnO_2 to Mn_3O_4.

Ferro-manganese has of recent years also been manufactured in the electric furnace. One of the drawbacks of ferro-manganese for some purposes is the large amount of carbon it contains. A recent paper by Messrs. E. G. L. Roberts and E. A. Wraight[1], entitled 'The Preparation of Carbon-free Ferro-manganese', describes experiments carried out to determine the commercial possibility of refining ordinary ferro-manganese; the authors consider that the most hopeful method consists in treating the molten alloy with manganese oxide. The paper is valuable for the review it gives of the attempts to make metallic manganese and to manufacture and refine ferro-manganese.

I have given the foregoing brief account of the manufacture of ferro-manganese, because the question of the manufacture of this alloy in India has already arisen, and because it is very difficult to get any definite information on the subject. The details of the manufacture seem to be more or less secret. From the figures given above, however, we can form a rough idea as to the possibility of manufacturing ferro in India. Let us take the average ore of the Central Provinces to contain:—

Manufacture of ferro-manganese in India.

Manganese	52
Iron	7
Silica	6½
Phosphorus	0·10

Assuming that the loss of manganese in smelting this, without admixture with any other ores, would be 20%, then the composition of the ferro obtained would be:—

Manganese	79·2
Iron	13·3
Carbon and silicon	7·5

assuming the total of carbon and silicon to be that given in the last line. By picking out the less ferruginous ores the ferro-manganese could easily be raised to the 80% grade if this were desired. Assuming that for every ton of ferro-manganese 2½ tons of Giridih coke would be required, then as this contains about 14 % of ash, which we can assume as equivalent to 6% of silica[2], the total amount of limestone required for fluxing the

[1] *Jour. Iron Steel Inst.*, No. II for 1906, pp. 229 286.
[2] No analyses of the ash of Indian coals seem to be available.

silica in both the ore and fuel would be 0·98 ton for each ton of ferro-manganese made. Hence the total charge would be in the following proportions for every ton of 79% ferro made :—

Manganese-ore	1·9 tons
Coke	2·5
Limestone	1·0

Now the average price for first grade ore from 1901 to the beginning of 1908 has been 11·13 pence per unit of manganese. Let us take 11 pence. The *c.i.f.* value of 52% ore at United Kingdom ports would therefore be Rs. 35-12 per ton on the average ; allowing Rs. 13-4 (see table 50) as the cost of sending this ore from Bombay to England, the *f. o. b.* or export value at Bombay would be Rs. 22-8 per ton. Let us assume, for the sake of a concrete example, that it is proposed to make the ferro-manganese at Sini, Bengal-Nagpur Railway. As this place happens to be about the same distance (521 miles) from Kámthi as Bombay is (529 miles), Kámthi ore delivered at Sini would have to be paid for at the export value at Bombay, namely Rs. 22-8 per ton. The coke would probably not cost more than Rs. 16 per ton [1] in wagons at Sini. The cost of the limestone I do not know ; but it would probably not be more than Rs. 5 delivered at Sini, especially if the Bisra limestone should prove suitable. Hence the cost of the materials necessary for the production of one ton of ferro-manganese is as follows :—

	Rs.	*a.*
1·9 tons of manganese-ore	42	12
2·5 tons of coke	40	0
1·0 tons of limestone.	5	0
	87	12

Now the average market price of ferro-manganese at Pittsburg during 1901 to 1907 as quoted in the *Engineering and Mining Journal* is $61·37 or Rs. 191-12. It would probably cost Rs. 18 to 20 to send the ferro-manganese from Sini to the European and American markets. Assuming the latter figure, the average value of the ferro at the works at Sini would be Rs. 171-12. The difference between this and Rs. 87-12, the cost of the materials, is Rs. 84. From this has to be deducted the costs of smelting the charge for the production of the ferro and all the other charges, such as depreciation on plant

[1] The figure given me by Mr. H. Macleod, for 1907, when prices were high.

and interest on capital laid out. What is left after making this deduction is the approximate profit per ton of ferro-manganese manufactured. I have no information as to costs of plant, smelting, etc., and consequently cannot give a figure for this deduction. The market price for pig iron in England in the early part of 1908 has ranged from 48 to 50 shillings; this has of course to cover the manufacturer's total costs of materials and smelting, interest on capital, etc., and his profit, though the latter may have been small at this time. Since ferro-manganese is smelted in a similar way to pig iron, even though the wear of the furnace is greater, and men who understand the manufacture of ferro may be able to command higher salaries, it is not probable that the deduction that has to be made from the figure of Rs. 84 given above is greater than Rs. 30, and not at all improbable that it is considerably less. Hence it will be seen that even though the figures I have given are very rough, yet there seems to be room for a handsome profit in manufacturing ferro-manganese in India; and it certainly looks as if it should be worth some one's while to go seriously into the question.

Use of spiegeleisen and ferro-manganese.

These two alloys, spiegeleisen and ferro-manganese, are used chiefly in the Bessemer and open-hearth processes for making both acid and basic mild steel. In all cases they are added at the end of the process. The alloy may either be charged direct into the furnace, or it may be put in the launder through which the molten metal runs on being tapped from the furnace into the casting ladle, or it may be put into the casting ladle itself. On account of the requisite time (5-12 minutes) and temperature conditions being obtained and a more thorough mixing being effected, with a consequent more uniform product, the first method is preferred by some.[1] The reason for the addition of the alloy is twofold :—

(1) To supply the carbon requisite to convert the metal, which has become decarburized in the furnace, into steel.

(2) To remove the oxygen taken up by the bath of molten metal with the formation of oxide of iron.

Quantity of manganese required in the manufacture of steel.

All the manganese concerned in this process of breaking up the iron oxide passes into the slag as manganous oxide. But, as will be seen from page 592, a certain proportion of manganese in the finished steel is

[1] *Iron and Steel Mag.*, IX, May 1905, pp. 474—5.

beneficial; hence it is necessary to add a quantity of alloy sufficient for some manganese to be left in the steel after the removal of the oxygen. Penrose says that the amount of the alloy added varies from 1 to 5% of the steel, according to its metallic contents, and according to the amount of manganese it is desired to leave in the steel. The amount left in ordinary mild steel, such as is used for rails, varies from less than 0·5% to over 2%, but is not as a rule much over 0·5%. As the manganese alloy always contains silicon and phosphorus and other impurities, the less of it that has to be added the better; also the less that has to be added the milder can the resulting steel be made. Hence high-grade ferro-manganese is usually preferred to the lower grade spiegeleisen.

In paper on the covering of the demand for manganese-ores[1], W. Venator takes an average consumption in the iron and steel industry of 1·3% of manganese as necessary per ton of steel produced. The 50,000,000 tons of steel produced by the world in 1906, would thus account for a consumption of 650,000 tons of manganese, or 1,300,000 tons of 50% manganese-ore, out of the 1,445,000 tons of ore produced in that year.

Phosphorous and silicon in spiegeleisen and ferro-manganese.

As regards the impurities permissible in the alloy used O. Simmersbach gives it as a rule that spiegeleisen with 20% Mn should not contain more than 0·1% of phosphorus, and for every 10% Mn above this the phosphorus contents should not increase by more than 0·02%, so that ferro-manganese with 80% Mn should not contain more than $0{\cdot}1+(6\times0{\cdot}02)=0{\cdot}22\%$ P. The standard for silicon is spiegeleisen containing 20% Mn and 1% Si with a permissible increase of 0·1% Si for every 10% increase in the manganese; hence 80% ferro-manganese should not contain more than $1{\cdot}0+(6\times0{\cdot}1)=1{\cdot}6\%$ silicon. From the above we see that ore of the composition given on page 586 should not, if it is to give 80% ferro, contain more than 0·116% or, say, 0·12% of phosphorus. The average figure for phosphorus given there is 0·10. This is possibly a trifle higher than that of the ore exported; 0·08 to 0·09 would probably be a more accurate figure. The ores of the Central Provinces are therefore within the phosphorus limits necessary for high grade ferro. Of ores exported from other parts of India, those of Mysore and Sandur are well within the limits. But those of Jhábua (0·16-0·27% P) and the Panch Maháls (0·15-0·25% P) are over the limit, and those of

[1] 'Die Deckung des Bedarfs an Manganerzen', *Stahl. u. Eisen*, XXVI. p. 66, (1906)

Vizagapatam (0·20-0·45% P) very much so. The question then arises as to what use is made of these ores. Now for the preparation of 20% spiegel it would take ·309 tons of manganese-ore of composition

Manganese	45
Iron	10

assuming a loss of 25% of manganese in smelting, to give one ton of 20% spiegel, the remainder of the charge being made up of iron-ore in requisite quantity (1·36 tons if containing 50% of iron, and the loss in smelting were *nil*). If the iron-ore were absolutely free from phosphorus then the maximum possible phosphorus in the manganese-ore, so that the spiegel should not contain more than 0·10% of phosphorus would be 0·18%. Hence we see that some of the Jhábua and Panch Mahál ores could be used for spiegel, but not those of Vizagapatam.

It is to be noted, however, that although Simmersbach gives 0·22% P as the upper limit that 80% ferro-manganese should contain, he gives analyses of ferro-manganese from various localities showing 0·20-0·36% P with 76-85% Mn. Other analyses often show figures in excess of those given by Simmersbach as permissible. Thus Penrose gives analyses of spiegeleisen showing 0·002-0·196% P with 8-26% Mn; and analyses of ferro-manganese showing 0·005-0·471% P with 40-88% Mn. The above deductions as to the employment of the ores of Jhábua and the Panch Mahál should therefore be taken with reserve.

Use of the Indian phosphoric ores.

I am told that a considerable proportion of the Indian phosphoric ores is used in the manufacture of basic mild steel by the Thomas-Gilchrist process, and probably in the basic open-hearth process as well; but whether it is used in the manufacture of the pig required for this process or whether it is put into the charge in the steel furnace, I have not heard. In either case the excessive amount of phosphorus would pass into the slag along with the phosphorus derived from the iron-ores. For use in this way Indian phosphoric manganese-ores find their way to England, Germany, and America.

Use of manganese-ore for de-sulphurizing.

Now manganese has a great affinity for sulphur and is consequently used as a de-sulphurizer. I understand that a considerable quantity of Indian phosphoric ore is used in the smelting of the highly phosphoric low-grade oolitic iron-ores ('minettes') of Luxemburg and Lorraine, the manganese-ore being put into the blast-furnace charge; the

product is a phosphoric nonsulphurous pig, the manganese having combined with the sulphur, which I am told these ores contain in considerable quantity, and carried it into the slag. This pig is converted into steel by the basic process.

There is also a process known as J. Massenez' de-sulphurization process. In this the cast iron is tapped out of the furnace into a ladle or 'mixer' to which an iron-manganese alloy containing the required amount of manganese is added. On allowing to stand at rest for some time the manganese combines with the sulphur in the iron and floats to the surface, as manganese sulphide. The slag may be returned to the blast-furnace, when the greater part of the sulphur is eliminated and the manganese recovered.[1]

Manganese in foundry practice.

Manganese is also sometimes used in foundry practice. The presence of manganese in foundry pig, if not over 1 to 2%, is beneficial because it makes the pig harder and closer grained; it is also indirectly useful because it prevents the absorption of sulphur from the coke during remelting. It may be added in the form of ferro-manganese or of ore.[2] When added in small quantities to the molten metal in a foundry ladle the immediate effect may be the softening of the iron, owing to the manganese eliminating the sulphur and counteracting the effect of silicon.[3]

Manganese-steel.

Manganese-steel contains a considerably higher percentage of manganese than is present in all ordinary steels. Proportions of manganese from 1 to 7% are said to render steel brittle; but when the manganese is present in the proportions of 7 to 30% the steel becomes remarkably strong and ductile, both toughness and ductility being increased without loss of hardness, by heating to a yellow or white heat and quenching in water. Manganese-steel thus contrasts with carbon steel; for in the latter great hardness is produced only on quenching and is accompanied by brittleness and less ductility. Besides combining great toughness with great hardness, manganese-steel is practically non-magnetic. It is also remarkable for its extremely low electric conductivity, so that it might be used for resistance coils. It is also a very bad conductor of heat. These alloys were investigated by Hadfield, who patented steel with amounts of manganese between 7 and 20%. The well-known Hadfield Era Steel is said to contain about

1 Turner, 'Metallurgy of Iron', pp. 151-2, (1895).
2 F. Wüst, *Jour. Iron Steel Inst.*, 1903, No. II, pp. 646-8.
3 Turner, *loc. cit.*, p. 205

13% of manganese and 1% carbon. Although, on account of its hardness, very difficult to work, manganese-steel is now being used extensively for many purposes where combined hardness, toughness, and consequent great ability to resist grinding wear, are required. Among such applications may be mentioned all kinds of mining machinery, especially that used for crushing and milling, such as the jaws of rock-breakers, crusher-heads, rolls, etc., and also mine-car wheels, dredging machinery, and safes. Manganese-steel rails are used in America on the Boston Elevated Railway[1] wherever there are sharp curves, with consequent great wear of the rails. The manganese-steel rails are found to be more economical than either carbon-steel or nickel-steel rails, owing to their excessively slow rate of wear. Manganese-steel has also been used for tools, such as axes and razors.

Effects of manganese on iron and steel.

The above gives only a brief outline of the uses of manganese in the metallurgy of iron and steel. The effects of manganese on iron and steel have been summarized by H. M. Howe[2] as follows:—

'It is easily removed from iron by oxidation, being oxidized even by silica, and partly in this way partly in others it restrains the oxidation of the iron, while sometimes restraining sometimes permitting the oxidation of the other elements combined with it. It is also apparently removed from iron by volatilization. Its presence increases the power of carbon to combine with iron at very high temperatures (say 1400°C), and restrains its separation as graphite at lower ones..... .....By preventing ebullition during solidification and the formation of blow-holes, by reducing or removing oxide and silicate of iron, by bodily removing sulphur from cast-iron and probably from steel, by counteracting the effects of the sulphur which remains as well as of iron-oxide, phosphorus, copper, silica and silicates, and perhaps in other ways, it prevents hot-shortness, both red and yellow. (It does not however counteract the cold-shortness caused by phosphorus.) These effects are so valuable that it is to-day well nigh indispensable, though admirable steel was made before its use was introduced by Josiah Marshall Heath[3].

It is thought to increase tensile strength slightly, hardness proper, and fluidity, to raise the elastic limit, and, at least when present in considerable quantity, to diminish fusibility. It is generally thought to diminish ductility: evidence will be offered tending to show that its effects in this respect have been exaggerated. While 1·5 to 2·5% of manganese is nearly universally admitted to cause brittleness, steel with 8% of manganese is astonishingly ductile: with further increase of manganese the ductility again diminishes. Steel with 8 to 10% manganese, though extremely tough, is so hard as to be employed without quenching for cutting-tools. It is denied and asserted with equal positiveness that manganese confers the power of becoming harder when suddenly cooled, but it is generally thought to make steel crack when quenched.'

[1] *Iron and Steel Mag.*, IX, pp. 476-481, May 1905. Abstracted from *Railroad Gazette*, March 17, 1905.

[2] 'The Metallurgy of Steel', I, p. 42, (1891).

[3] Percy: Iron and Steel, p. 840.

Roberts-Austen explains the effect of manganese on steel in the following manner :—

Manganese having a lower atomic volume (6·9) than iron (7·2) delays during cooling the change from the β, or hard allotropic variety of iron into the α, or soft variety, as well as that of hardening carbon into carbide carbon. Hence with equal rates of cooling it tends to increase the proportion of β-iron present in cooled iron and steel, and consequently the hardness of the metal[1]. 'Speaking generally, if the steel contains, in addition to carbon, $\frac{5}{10}$ per cent. of manganese, each class of steel would be equivalent, as regards tenacity and hardening properties, to the one above it', *i.e.*, it would be equivalent to a steel with more carbon[2]. Above 7% of manganese appears to prevent entirely the passage of β-iron into α-iron, and since β-iron cannot be magnetized—the temperature of recalescence, at which iron in cooling down changes from the β to the α form, being also that at which iron on heating up loses the power of being magnetized and passes from the α to the β form—, steels with over 7% of manganese are non-magnetizable. Ewing concludes that 'no magnetising force to which the metal is likely to be subjected, in any of its practical applications, would produce more than the most infinitesimal degree of magnetisation' in Hadfield's manganese-steel.[3] That high manganese may to a certain extent counteract the deleterious effects of phosphorus is explained by the fact that the manganese phosphide has the formula Mn_3P_2, whilst that of the iron phosphide is Fe_3P, so that the manganese can take up twice as much phosphorus as the iron. When in the phosphide condition the phosphorus is less injurious to the mechanical properties of the steel than when evenly disseminated through the steel.[4]

Hadfield[5] has recently patented a manganese-steel containing 10-40% manganese and less than 1% carbon. It is prepared by the addition to decarburized iron of ferro-manganese, made in the electric furnace, and containing only 2-3% of carbon. Owing to the comparatively low percentage of carbon in the steel, it is less liable to fracture during treatment. It is also distinguished by its relatively strong magnetic characters.

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1 'Introduction to the Study of Metallurgy', p. 121, (1902).
2 *Loc. cit.*, p. 176.
3 *Loc. cit.*, p. 171.
4 J. A. Mathews, 'Mineral Industry', XI. p. 673.
5 *Electrochemical and Metallurgical Industry*, July 1907, p. 283.

Other manganese alloys.

In addition to spiegeleisen and ferro-manganese there is a large number of other alloys containing manganese.[1] An interesting account of the alloys containing manganese is given by Penrose in his book on manganese, and to this reference may be made. Since this was written, however, much work has been done on alloys containing manganese. Attention may be drawn to Heusler's magnetic alloy of copper, manganese, and aluminium[2], and to Guillet's work on nickel-manganese steels.[3] The only alloys that can be mentioned here in addition to those already noticed are silicon-spiegel and manganese-bronze.

Silicon-spiegel.

For some purposes alloys of iron rich in both manganese and silicon are required. Such alloys are known as *silicon-spiegel* and *silicon-ferro-manganese*. An example of silicon-spiegel is an alloy containing 10% silicon and 20% manganese. The name *manganese-bronze* is applied to alloys of manganese and copper, sometimes with iron as well. In commerce there are now two grades of metal.

Manganese-bronze.

One is a mixture used for rolling into sheet, or drawing into wire or tubes, and also for forging. It contains no aluminium and cannot be cast in sand. The other grade contains aluminium, and is suitable for sand-casting, being largely used for the manufacture of ship's propellers. Both these grades apparently also contain zinc.[4] Manganese-bronze is distinguished by a remarkable strength, toughness, and hardness, and by a non-liability to corrosion by sea-water; hence its use for propellers.

Metallic manganese.

Metallic manganese also is now manufactured on a commercial scale, namely at Essen in Germany, the Goldschmidt process of reduction by aluminium being used. Owing to its high cost as compared with ferro-manganese (about 10 to 1) its use is limited mainly to the manufacture of copper and other special alloys[5]. The price is quoted in the *Engineering and Mining Journal* for January 25th, 1908, page 239, as 75 cents per lb., at New York, for metal containing 98-99 % Mn.

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1 In the *Iron and Coal Trades Review*, June 29th, 1906, pp. 2316, 2317, there is an interesting article entitled 'Some Uses of Pure Manganese and its Alloys.'

2 *Eng. Mining Journal*, 13th Jan. 1906, p. 84: B. V. Hill, *Electrician*, Nov. 24, 1905; A. D. Ross, *Proc. Roy. Soc. Edin.*, XXVII, pp. 88-92, (1907).

3 *Revue de Métallurgie*, Nov. 1905. Abstract in *Iron and Steel Mag.*, XI, April 1906, p. 329.

4 *Eng. Mining Jour.*, 8th Sept. 1906, p. 458.

5 'Mineral Industry', X, p. 441, (1901).

The smelting of manganese-ores by the natives of India.

Iron-ores occur in great abundance in many parts of India and have been smelted from time immemorial by the natives. It is interesting to note that in some cases the ores smelted have been manganiferous, sometimes highly so. Whether the use of manganiferous ores was dependent on local occurrence and hence merely accidental, it is difficult to say. But, judging from the fact that in some cases true manganese-ores have been mixed in with iron-ores in the furnace, it seems probable that in these cases at least the native smelters have recognized that the addition of this constituent has some beneficial effect on the quality of the iron produced. Thus I found that the Dhávads or iron-smelters of Mahábaleshwar in the Western Ghâts have a separate name—*aural*—for manganese-ore, and that in former days, before smelting was stopped here on account of the damage done to the forests, some of the manganese-ore was used in the charge. This was on the authority of two Dhávads who had formerly smelted in the times when this industry was flourishing. A writer in the *Indo-European Commercial Trade Register*[1] refers to a tradition amongst the Dhávads that the Phœnicians used to carry away manganese-ores. Mr. H. G. Turner, taking as his evidence the occurrence of vestiges of furnaces close to Garbhám Hill[2], says that the manganese-ores of Garbhám in the Vizagapatam district were formerly worked by the native smelters. The example best known in India is the smelting that at present goes on at Ghogra in the Jabalpur district. Here a manganiferous iron-ore is smelted in small native iron-furnaces; the product is a rather hard steely iron known as *kheri*, and is in great demand in the surrounding country, where the *lohárs* or blacksmiths weld it on to ordinary country-made soft iron to form the edges of axes and scythes, the striking faces of hammers, and the heads of anvils. As an example of the demand for this metal I may mention that when I was at Ghogra I found some blacksmiths who had come all the way from Rewah simply to get a fresh stock of this *kheri*. The ore from which the iron is smelted is a manganiferous micaceous hematite, the manganese occurring as veinlets and films of psilomelane in the hematite, into which it has been secondarily introduced. Some of the ore I saw being selected for smelting was pure psilomelane, however. The shallow pits from which the ore is obtained are in Dhanwáhi village limits. Mallet

Kheri.

[1] I, p. 47, (1907).
[2] *Jour. Iron Steel Inst.*, No. II for 1896, p. 180.

some years ago took a sample from the whole of these pits and obtained the following result on analysis[1]:—

Manganese	12·26[2]
Iron	46·43
Silica, etc.	9·55
Phosphorus	0·19
Sulphur	trace

When at Jauli, in the same district, I took a sample of the soft hematite being smelted there for the production of the soft iron on to which the *kheri* is welded. The analysis, made by Messrs. J. & H. S. Pattinson of Newcastle, is given below :—

Sample No. A. 10.

Manganese	0·16
Iron	59·90
Silica	5·80
Phosphorus	0·043

Samples taken from the rough blooms of *kheri* and soft iron produced from these ores were analysed by the same firm of analysts with the following results :—

TABLE 89.

Analyses of native-made irons.

	Kheri from Ghogra.	Soft iron from Jauli.	Iron shot from Jauli.
Iron	98·253	99·247	95·407
Manganese	0·296	trace	0·086
Carbon	1·214	0·378	3·918
Silicon	0·095	0·327	0·235
Phosphorus	0·140	0·039	0·333
Sulphur	0·002	0·009	0·021
	100·000	100·000	100·000

The third sample represents some round shot found amongst the ashes and charcoal left after the bloom has been taken out of the furnace. From these analyses it will be seen that the superior hardness of the *kheri* over the soft iron can hardly be attributed to the 0·3% of manganese it contains ; but must rather be attributed to the larger amount of carbon. The manganese has no doubt had a purifying effect on the *kheri*

1 *Rec. G. S. I.*, XVI, p. 101, (1883).
2 Contains traces of cobalt.

in the same way as in the manufacture of mild steel, whilst the manganese left in the *kheri* may exert some effect in keeping the carbon in the combined condition. It is to be noted, however, that although the *kheri* is much superior in hardness to the soft iron, so that the faces of the hammers and anvils assume a smooth shining mirror-like appearance under the influence of constant impact, yet one of these shining surfaces was easily dented by the corner of my geological hammer. Of the manganese in the iron-ore from which the soft iron is manufactured, it will be seen that practically all has left the iron and has hence passed into the slag, except for a small portion found in the shot. I did not see the use to which the shot are put, but I was told that they are made into plough-shares, the iron thus made being harder than the soft iron, but more liable to break. If the composition of the finished metal be like that of shown by the analysis, the ploughshare metal must be intermediate between cast iron and steel. An account of the manufacture of *kheri* is given by P. N. Bose[1].

Use as an Oxidizer.

Use of manganese as an oxidizer.

We can now turn to the use of manganese-ore as an *oxidizer*. For this purpose the value of the ore does not depend on the amount of manganese it contains, but on the amount of *available oxygen*, *i.e.*, oxygen that can be obtained from it by the action of acids. This available oxygen is usually stated in terms of manganese peroxide (MnO_2). The mineral containing the largest amount of MnO_2 is of course pyrolusite, which when pure consists of 100% of MnO_2.[2] Psilomelane, also, often contains a considerable quantity of MnO_2. Psilomelane is, as noted in Chapter IV, a manganate corresponding to the general formula R_2MnO_5. If the R consisted entirely of manganese, giving a formula for the mineral of Mn_2MnO_5, then the amount of MnO_2 present in the theoretically pure mineral would be 77·33%. Going to the other extreme, if the R consisted entirely of hydrogen, a condition not approached even nearly in Nature, then the formula of the compound would be H_4MnO_5, and the amount of MnO_2 in the theoretically pure compound would be only 62·57%. But it will be seen that after deducting $2H_2O$, the radicle MnO_3 is left; in this case, therefore, it would be misleading to state

1 *Rec. G. S. I.*, XXI, pp. 87, 88, (1888).

2 Polianite also has this formula, MnO_2, but it is too rare to be considered commercially.

the available oxygen in terms of MnO_2, the amount of available oxygen being in fact equivalent to $2 \times 62{\cdot}57\%$ of MnO_2. On the assumption of R being entirely Ba, so that the formula would be Ba_2MnO_5, the MnO_2 works out at $21{\cdot}23\%$, but the available oxygen is equivalent to $2 \times 21{\cdot}23 = 42{\cdot}46\%$ MnO_2. Hence it will be more convenient to state the available oxygen as such in the way given below :—

TABLE 90.

Available oxygen and manganese peroxide present in pyrolusite, psilomelane, and hollandite.

Formula.	Pyrolusite.	Psilomelane (and hollandite).		
	MnO_2.	Ba_2MnO_5	Mn_2MnO_5.	H_4MnO_5.
Available oxygen . .	18·39	7·81	13·06	23·01
MnO_2 equivalent of available oxygen . .	100·00	42·46	77·33	125·14
MnO_2 present . . .	100·00	21·23	77·33	62·57

From this it will be seen that in theoretically pure psilomelanes the amount of available oxygen should range between the limits of 7·81 and 23·01. Since in most psilomelanes the bulk of the R group is manganese, the majority of psilomelanes should range round 13% in their available oxygen, this corresponding to about 77% of MnO_2. Allowing for the fact that most psilomelanes contain a little mechanically-included impurity these figures would be in actual practice a little less than 13 and 77, respectively. The 5 analyses of psilomelane given in Chapter IV show 70·78 to 83·13% MnO_2, whilst the 12 calculated analyses show from 73·14 to 84·12% MnO_2. The four analyses of hollandite, to which the foregoing figures as to composition also apply, show 65·63 to 75·05% MnO_2.

As is shown below the other ores of manganese contain much smaller amounts of MnO_2 :

	% MnO_2.
Manganite	49·44
Braunite	43·11
Hausmannite	37·99
Rhodochrosite	*Nil.*

The standard ore for chemical purposes is that containing 70% MnO_2 equivalent to 44·25% manganese, and below this limit there is not much demand for ores for these purposes. Hence we see that for chemical

purposes the best ore is pyrolusite, but that psilomelane is often good enough; whilst the other ordinary ores of manganese are of little or no use.

The chief chemical use of manganese-ore is for the manufacture of chlorine, and before the use of manganese in the metallurgy of iron and steel, this accounted for by far the larger proportion of the consumption of manganese-ore. Of recent years, however, the demand for manganese-ores for the manufacture of chlorine has decreased owing to the manufacture of chlorine electrolytically. For chlorine manufacture not only must the ore be as high in MnO_2 as possible, but the impurities making up the remainder of the ore should be such as are insoluble in hydrochloric acid. Thus ore containing 75% manganese peroxide would be of more value if the remaining 25% were quartz, than if it were iron oxide or carbonates. Owing to the fact that soft ores are more quickly attacked by acid than hard ones, pyrolusite is preferable to psilomelane, even when the two contain the same percentage of MnO_2. There are many deposits in India where a fair quantity of pyrolusite, ranging over 70% of MnO_2, can be obtained; and at times Indian pyrolusitic ores have been sold for chemical purposes. Thus some of the Kodur pyrolusite is said to have been bagged and sold for this purpose, as also has some of the Mysore ores. The analysis of a picked specimen of Kodur pyrolusite given on page 82, shows 92·31% MnO_2: whilst bulk samples of pyrolusitic ores from Bankuravalsa and Sandanandapuram in the same district show 71·64 and 72·03% MnO_2 respectively (see pages 1105 and 1076). And if it were specially required I believe that at several localities a product of over 80% of MnO_2 could be sorted. It must be remembered that ore sold for its MnO_2 contents fetches a much higher price than if sold for its manganese contents. In the following table the figures given in the first and second columns are taken from the *Engineering and Mining Journal* for August 3, 1907, page 236, and refer to crude powdered ore. In the third column I have converted the price in cents per pound into sterling per ton:—

TABLE 91.

Prices of manganese-ores sold for peroxide.

Percentage of MnO_2.	Cents per pound.	Sterling per ton.
		£ s. d	£ s. d.
70–75	1¼-1½	5 16 8 to	7 0 0
75–85	1½-2	7 0 0 to	9 6 8
85–90	1¾-5	8 3 4 to	23 6 8
90–95	6½	worth £30	6 8

When it is remembered that even if the ore contained 95% MnO_2, which is equivalent to 60% of manganese, and were sold for its manganese at 16 pence per unit, it would fetch only £4 a ton, *i.e.*, less than ore containing only 70% of MnO_2 equivalent to only 44% manganese, if sold for its MnO_2, it will be seen that the extra cost of bagging the ore would be handsomely repaid; and considering the great increase in the price for the higher grades, it would probably pay to concentrate the ore before shipping.

Use of manganese for the decolourization of glass.

Another use to which manganese-ore is put on account of its oxidizing power is the decolourization of glass[1], from which it removes the green colour due to ferrous iron. Pyrolusite for this purpose must be extremely pure—iron being of course a very deleterious constituent—and fetches a very high price. The only pyrolusite sufficiently pure for this purpose, yet found in any quantity in India, is that of Páli in the Nágpur district. A picked specimen of this (see No. 932 on page 82) yielded on analysis 95·57% MnO_2 with only 0·06% Fe_2O_3. Of ore similar to this, a sufficient quantity could probably be won to pay handsomely for the trouble of extracting it from the limestone in which it occurs in scattered pockets. A bulk sample of ore not specially selected for this purpose gave 72·71% MnO_2, with still only 2·98% Fe_2O_3.

A well-known region from which high-grade pyrolusite has long been obtained suitable for use for chemical purposes and for the glass industry is Nova Scotia and New Brunswick. Some of the ores from this region are exceptionally high in MnO_2 and low in iron. The less pure ores are often prepared for the market by crushing, washing, and sizing with screens.

To give an idea of the high prices that the Canadian ores fetch I give below a table showing the official statistics for the quantity and value of the Canadian production of manganese-ore from the years 1893 to 1905; the values per ton for each year are shown in the last column. It will be seen from this that the value of the Canadian ores has fluctuated during this period from a maximum of £19-12-3 per ton in 1893 to a minimum of £2-5-7½ in 1901, the value for the last year for which I have

[1] According to *Knowledge and Scientific News*, October 1907, p. 230, the use of manganese oxide as a decolourizer of glass was known to the Romans, colourless glass becoming popular about the first century A.D. A specimen of colourless glass, unearthed at Saalburg, near Hamburg, and of Roman origin, showed 0·36% of manganese oxide and 0·49% of iron oxide.

obtained figures being £16-5-9. The violent fluctuations are probably due to great variations in the quality of the ore, rather than to variations in price. And it must be remembered that the price for any given year is probably below that of the best ore, because the value is calculated on the whole of the ore produced.

TABLE 92.

Quantity and value of the Canadian manganese-ore production from 1893 to 1905.

	Quantity.	Total value.	Value per ton.
	Tons.	$	$
1893	133	12,521	94·14
1894	56	3,120	55·71
1895	108·3	6,351	58·64
1896	123·5	3,975	32·19
1897	15·25	1,166	76·46
1898	11	325	29·55
1899	70	2,410	34·43
1900	34	1,720	50·59
1901	440	4,820	10·95
1902	172	4,062	23·62
1903	135	1,889	13·99
1904	123	2,706	22·00
1905	22	1,720	78·18

Use of manganese for bleaching powder, bullion melting, and potassium permanganate.

Manganese-ore might also be used for the preparation of bleaching powder in India, for which there would probably be a demand from the Indian paper mills. I also understand that manganese peroxide has been used on the Kolar Gold Field to assist in the oxidation of the zinc when the auriferous precipitates obtained in the cyanide process from the zinc boxes are being converted into bullion. Large quantities of potassium permanganate are used in India as a disinfectant. It is a pity that this material should be imported when the material, namely manganese-ore, from which it is made, exists in such abundance in India.

Use as a Colouring Material.

Use of manganese for colouring glasses and enamels.

From very early times there has probably been a small consumption of manganese-ore by the natives of India for colouring glasses and enamels, it being possible to impart green, violet, brown, and

black tints by the use of this substance. According to Sir George Watt[1] the colours in the Indian enamels are invariably due to borates and silicates of the metals, manganese carbonate being used to produce violet. The pyrolusite of Gosalpur in the Jabalpur district is supposed to have been worked from ancient times for use by glass-workers as a colouring material. Watt[2] gives an interesting account of the ornamentation of the pottery of Peshawar. He says :—

Use of manganese for pottery.

'The pottery of this northern town has been spoken of as resembling majolica. It is a rough "*faience*". The reddish earth body or "paste" is coated with a dressing in white earth—the "slip" or "*engobe*" which consists of a preparation of *karia mitti* or chalk, obtained from the Khaibar. It is then dipped into the glaze of which the basis is lead oxide. For the ordinary greenish white pottery, nothing else is needed. But when it is desired to ornament the plate or jar, the design is outlined on the unburnt glaze, with a paint made of manganese, and the details are filled in with a preparation of copper. When burned, green leaves, outlined in brown, are produced on a dirty white. Sometimes the glaze is more thoroughly fused and the colours then run and the brown takes a purplish tint. Further colours are red, obtained from a red earth, and black, from a stone of dark colour—both procured from the Khaibar.'

The dark ore last referred to may very well be an ore of manganese.

At Rániganj, Messrs. Burn & Co. use manganese-ore to a small extent for imparting dark brown and black body colours to tiles and pottery, and also for imparting dark brown and black glazes to ordinary biscuit-ware. Formerly, inferior black tiles were produced without the use of manganese, the black colour being obtained by using disintegrated laterite with a little salt—not enough to glaze—added at a high heat, a reducing atmosphere being maintained. But about 20 years ago the use of manganese-ore was begun with the production of a very superior black colour.

The mixture used by Messrs. Burn & Co. in 1904 for producing black tiles is the following :—

	Parts by measure.
Black biscuit	3
Kankar[3]	2
Durgapur clay	2
Manganese-ore	3
Felspar	2

The material all passes a sieve of 40 holes to the linear inch. By using half the quantity of manganese-ore, a chocolate-coloured tile is obtained.

1 'Indian Art at Delhi', p. 22. (1903).
2 *Loc. cit.*, p. 89.
3 Really disintegrated laterite.

The next recipe is that in use for a black body clay for plaster moulds and the potter's wheel :—

Recipe No. 63.

	Parts by measure.
Black broken pipes	3
Uncalcined kankar [1]	2
Durgapur clay	2
Giri mati (red ochreous clay)	2
Manganese-ore	1
Then take of	
Recipe No. 63	3
Felspar and biscuit mixed	1

The materials are all passed through a small washmill and sieve of 120 holes to the linear inch. This latter recipe is used for producing statuary, vases, jeroboams, and other ornamental ware. When unglazed this ware is very similar in colour to psilomelane, emits a bell-like sound when struck, and is extremely hard and tough. Just the merest trace of glazing changes the colour to slaty-black, and when adorned with silver monogram, or other silver ornamentation, articles of this ware are exceedingly handsome.

Manganese-ore is also used for glazing terra-cotta biscuit-ware, the colour produced varying, according to the proportion of ore used, from chocolate to pure black. The following recipe is one now in use for imparting a deep brown glaze to such articles as teapots, chilams, and hookahs :—

	Parts by weight
White lead	$12\frac{1}{2}$
Cornish stone [2]	3
Calcined English flint	$2\frac{1}{2}$
Manganese-ore	$2\frac{1}{2}$
Durgapur clay	$1\frac{1}{2}$

By increasing the proportion of manganese-ore a deep black colour is obtained. Articles—presented by Mr. A. Whyte of Messrs. Burn & Co., to whom I am indebted for the foregoing information—illustrating the foregoing recipes will be found in the Geological Museum.

The ore used is all obtained from the neighbourhood of Sihora and Gosalpur in the Jabalpur district. The pyrolusite and psilomelane of this district are often mixed with quartz and clay ; but these foreign materials do not spoil the ore for pottery purposes, for which it need not be particularly pure.

[1] Really disintegrated laterite.
[2] Residue from Cornish kaolin.

Ornamental applications.

In addition to the manganese-ores proper, use might also be made of two of the Indian silicate minerals of manganese. In my paper 'Manganese in India', p. 120 [1], I wrote:—

'Moreover, I would draw attention to the fact that many of the manganese-ore deposits of the Central Provinces contain considerable quantities of rhodonite, at present being consigned to the dump-heap; but that the rhodonite from other parts of the world, especially the Ural Mountains, is often used as an ornamental stone. It would be difficult to find a more beautiful ornamental stone than the pink rhodonite with delicate veins of black manganese-oxide, such as occurs at Mánegáon, Nágpur district, or than the rhodonite studded with orange spessartite, such as is found at Chárgáon, Nágpur district, and in the Chhindwára district. In the United States, moreover, spessartite when found clear and transparent is sometimes turned to account as a very beautiful gem-stone of orange and red colours.[2] I have not seen any Indian spessartite, except very small crystals, sufficiently clear for this purpose, but it is as well to keep it in view'.

Since this was written Mr. H. D. Coggan, Manager of the Central India Mining Company, has kindly tried to obtain some large specimens of the rhodonite found in the Mánegáon deposit referred to above. He was not able to obtain anywhere pieces of rhodonite large enough for such purposes as the manufacture of small table-tops, because the rock was too much altered into manganese-ore. The specimens he obtained were nearly all of them interbanded with spessartite-rock, so that it would be difficult to select a piece of rhodonite more than 6 inches across. But if the banded rock could be used, fairly large pieces of rock might be obtained. As it is, however, a considerable supply of small pieces up to 6 inches across could easily be obtained, should anyone wish to start an industry for making small ornamental objects from rhodonite. And until some of the other deposits containing abundance of rhodonite have been carefully exploited, I shall not take it as demonstrated that it is impossible to obtain in India moderately large pieces of rhodonite suitable for ornamental work.

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[1] *Trans. Min. Geol. Inst. Ind.*, I, (1906).

[2] Kunz; 'Gems and Precious Stones of North America', p. 79, (1890).

APPENDIX TO PARTS I, II, AND III.

In this appendix I propose to give some figures that I have found extremely useful in making the calculation involved in turning analyses of minerals and ores into terms of their mineralogical composition, and in other calculations.

The atomic weights used throughout this Memoir are shown below :—

List of atomic weights.

Aluminium	27·1
Arsenic	75·0
Barium	137·4
Calcium	40·0
Carbon	12·0
Chlorine	35·45
Cobalt	59·0
Copper	63·6
Fluorine	19·0
Hydrogen	1·01
Iron	56·0
Lead	206·9
Magnesium	24·36
Manganese	55·0
Nickel	58·7
Oxygen	16·0
Phosphorus	31·0
Potassium	39·15
Silicon	28·4
Sodium	23·05
Zinc	65·4

Table showing the composition of certain manganese minerals.

Name of mineral.	Formula of mineral or compound.	Per cent. of Mn.	Log. of per cent. of Mn.	Per cent. of oxygen combined with Mn.	Log. of per cent. of oxygen.	Per cent. of other constituents.
Manganosite . .	MnO . . .	77·46	1·8891	22·54	1·3530	
Hausmannite . .	Mn_3O_4 . . .	72·05	1·8576	27·95	1·4464	
(Manganese sesquioxide).	Mn_2O_3 . . .	69·62	1·8427	30·38	1·4826	
Psilomelane ? . .	Mn_3O_5 ($2MnO.MnO_3$)	67·35	1·8283	32·65	1·5139	
(Pyrolusite and polianite).	MnO_2 . . .	63·22	1·8009	36·78	1·5656	
Manganite . . .	$Mn_2O_3.H_2O$ . .	62·50	1·7959	27·27	1·4357	H_2O = 10.23.
(Manganic manganate).	$2Mn_2O_3.3MnO_3$.	61·60	1·7896	38·40	1·5843	
(Manganese trioxide)	MnO_3 . . .	53·40	1·7275	46·60	1·6684	
Braunite . .	$8Mn_2O_3.MnSiO_3$.	63·59	1·8034	26·43	1·4221	SiO_2 = 9.98.
Rhodonite . .	$MnSiO_3$ . .	41·86	1·6218	12·18	1·0856	SiO_2 = 45.96.
Rhodochrosite .	$MnCO_3$ . . .	47·83	1·6797	13·91	1·1433	CO_2 = 38.26.
Spessartite . .	$3MnO.Al_2O_3.3SiO_2$.	33·24	1·5217	9·67	0·9854	SiO_2 = 36.50; Al_2O_3 = 20.59.

List showing composition of certain manganese minerals in terms of oxides.

Hausmannite	MnO	= 31·00	or 2 MnO	=	62·01
(Mn_3O_4)	Mn_2O_3	= 69·00	MnO_2	=	37·99
		100·00			100·00
Manganese sesquioxide			MnO	=	44·94
(Mn_2O_3)			MnO_2	=	55·06
					100·00
Psilomelane (?) or . . .	2 MnO	= 57·96	or 2 MnO	=	28·98
manganous manganate . .	MnO_3	= 42·04	MnO_2	=	71·02
(Mn_2MnO_5)		100·00			100·00

Manganic manganate	2 Mn_2O_3	=	50·56 or	MnO_2		97·44
($2Mn_2O_3.3MnO_3$)	3 MnO_3	=	49·44	Oxygen	=	2·56
			100·00			100·00
Manganite	Mn_2O_3	=	89·76 or	MnO	=	40·33
($Mn_2O_3.H_2O$)				MnO_2	=	49.43
	H_2O	=	10·24	H_2O	=	10·24
			100·00			100·00
Braunite	3 Mn_2O_3	=	78·29 or	MnO	=	46·91
($3Mn_2O_3.MnSiO_3$)	MnO	=	11·73	MnO_2	=	43·11
	SiO_2	=	9·98	SiO_2	=	9·98
			100·00			100·00
Rhodonite	MnO		54·03			
($MnSiO_3$)	SiO_2	=	45·97			
			100·00			
Rhodochrosite	MnO		61·74			
($MnCO_3$)	CO_2	=	38·26			
			100·00			
Spessartite	3 MnO	=	42·91			
	Al_2O_3	=	20·59			
($3MnO.Al_2O_3.3SiO_2$)	3 SiO_2	=	36·50			
			100·00			

List of factors for psilomelane and hollandite.

				Log of MnO_3 multiplier.
To form	$Fe_4(MnO_5)_3$	x Fe_2O_3 require	$x \times 0{\cdot}9656$ MnO_3 .	$\bar{1}{\cdot}9848$
	Fe_2MnO_5	x FeO	$x \times 0{\cdot}7153$.	$\bar{1}{\cdot}8545$
	$Al_4(MnO_5)_3$	x Al_2O_3	$x \times 1{\cdot}512$.	$0{\cdot}1796$
	Ba_2MnO_5	x BaO	$x \times 0{\cdot}3357$.	$\bar{1}{\cdot}5260$
	Ca_2MnO_5	x CaO	$x \times 0{\cdot}9196$.	$\bar{1}{\cdot}9636$
	Mg_2MnO_5	x MgO	$x \times 1{\cdot}276$.	$0{\cdot}1058$
	K_4MnO_5	x K_2O	$x \times 0{\cdot}5461$.	$\bar{1}{\cdot}7373$
	Na_4MnO_5	x Na_2O	$x \times 0{\cdot}8293$.	$\bar{1}{\cdot}9187$
	Co_2MnO_5	x CoO	$x \times 0{\cdot}6867$.	$\bar{1}{\cdot}8368$
	Ni_2MnO_5	x NiO	$x \times 0{\cdot}6894$.	$\bar{1}{\cdot}8385$
	Cu_2MnO_5	x CuO	$x \times 0{\cdot}6470$.	$\bar{1}{\cdot}8109$
	Pb_2MnO_5	x PbO	$x \times 0{\cdot}2310$.	$\bar{1}{\cdot}3636$
	Zn_2MnO_5	x ZnO	$x \times 0{\cdot}6327$.	$\bar{1}{\cdot}8012$
	H_4MnO_5	x H_2O	$x \times 2{\cdot}858$.	$0{\cdot}4561$
	Mn_2MnO_5	x MnO	$x \times 0{\cdot}7254$.	$\bar{1}{\cdot}8606$
	$Mn_4(MnO_5)_3$	x Mn_2O_3	$x \times 0{\cdot}9778$.	$\bar{1}{\cdot}9903$

Figures for the conversion of phosphoric oxide into phosphorus.

P_2O_5.	P.	P_2O_5.	P.	P_2O_5.	P.	P_2O_5.	P.	P_2O_5.	P.	P_2O_5.	P.
·01	·004	·21	·092	·41	·179	·61	·266	·81	·354	1·01	·441
·02	·009	·22	·096	·42	·183	·62	·271	·82	·358	1·02	·445
·03	·013	·23	·100	·43	·188	·63	·275	·83	·362	1·03	·450
·04	·018	·24	·105	·44	·192	·64	·279	·84	·367	1·04	·454
·05	·022	·25	·109	·45	·196	·65	·284	·85	·371	1·05	·458
·06	·026	·26	·113	·46	·201	·66	·288	·86	·375	1·06	·463
·07	·031	·27	·118	·47	·205	·67	·292	·87	·380	1·07	·467
·08	·035	·28	·122	·48	·210	·68	·297	·88	·384	1·08	·471
·09	·039	·29	·127	·49	·214	·69	·301	·89	·389	1·09	·476
·10	·044	·30	·131	·50	·218	·70	·306	·90	·393	1·10	·480
·11	·048	·31	·135	·51	·223	·71	·310	·91	·397	1·11	·485
·12	·052	·32	·140	·52	227	·72	·314	·92	·402	1·12	·489
·13	·057	·33	·144	·53	·231	·73	·319	·93	·406	1·13	·493
·14	·061	·34	·148	·54	·236	·74	·323	·94	·410	1·14	·498
·15	·065	·35	·153	·55	·240	·75	·327	·95	·415	1·15	·502
·16	·070	·36	·157	·56	·244	·76	·332	·96	·419		
·17	·074	·37	·162	·57	·249	·77	·336	·97	·423		
·18	·079	·38	·166	58	253	·78	·340	·98	·428		
·19	·083	·39	·170	·59	·258	·79	·345	·99	·432		
·20	·087	·40	·175	·60	·262	·80	·349	·100	·437		

Miscellaneous factors.

	Logarithm.
For *braunite*, multiply combined SiO_2 by 4·320 for the MnO_2 .	·6355
„ „ 4·700 „ MnO .	·6722

For *apatite*, 1 of P_2O_5 requires 1·314 CaO (including as CaO the $CaCl_2$ or CaF_2). To calculate chlorine or fluorine required multiply :—

	For Cl.	For F.
P_2O_5 by	·1664	·08929
CaO by	·1266	·06786

For *oxygen* required to form Mn_2MnO_5, multiply % Mn by $\frac{32·65}{67·35}$ = ·4848, of which the logarithm is $\bar{1}$·68556.

Tons and Poods.

1 Long ton = 2240 lbs.
1 Metric ton = 1000 kilogrammes = 2204·62 lbs.
1 Short ton = 2000 lbs.
1 Pood = 36·113 lbs.
1 Metric ton = 61·048 poods.

To convert	long tons	to	metric tons	multiply by	1·01605	of which log is	0·0069151
„	short tons	„	metric tons	„	0·90718	„	$\bar{1}$·9576935
„	poods	„	metric tons	„	0·0163806	„	$\bar{2}$·2143272
„	poods	„	long tons	„	0·0161219	„	$\bar{2}$·2074163

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VOL. VI, 1873.

Part 1.—Annual report for 1872. Geology of North-West Provinces.

Part 2.—Bisrampur coal-field. Mineralogical notes on gneiss of South Mirzapur and adjoining country.

Part 3.—Celt in ossiferous deposits of Narbada valley (Pliocene of Falconer) : on age of deposits, and on associated shells. Barakars (coal-measures) in Beddadanole field, Godavari district. Geology of parts of Upper Punjab. Coal in India. Salt-springs of Pegu.

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Part 4.—Fossil floras in India. Osteology of Merycopotamus dissimilis. Addenda and Corrigenda to paper on tertiary mammalia. Plesiosaurus in India. Geology of Pir Panjal and neighbouring districts.

Vol. X, 1877.

Part 1.—Annual report for 1876. Geological notes on Great Indian Desert between Sind and Rajputana. Cretaceous genus Omphalia near Nameho lake, Tibet, about 75 miles north of Lhassa. Estheria in Gondwana formation. Vertebrata from Indian tertiary and secondary rocks. New Emydine from the upper tertiaries of Northern Punjab. Observations on under-ground temperature.

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Part 4.—Geology of Mahanadi basin and its vicinity. Diamonds, gold, and lead ores of Sambalpur district. 'Eryon Comp. Barrovensis,' McCoy, from Sripermatur group near Madras. Fossil floras in India. The Blaini group and 'Central Gneiss' in Simla Himalayas. Tertiaries of North-West Punjab. Genera Chœromeryx and Rhagatherium.

Vol. XI, 1878.

Part 1.—Annual report for 1877. Geology of Upper Godavari basin, between river Wardha and Godavari, near Sironcha. Geology of Kashmir, Kishtwar, and Pangi. Siwalik mammals. Palæontological relations of Gondwana system. 'Erratics in Punjab.'

Part 2.—Geology of Sind (second notice). Origin of Kumaun lakes. Trip over Milam Pass, Kumaun. Mud volcanoes of Ramri and Cheduba. Mineral resources of Ramri, Cheduba and adjacent islands.

Part 3.—Gold industry in Wynaad. Upper Gondwana series in Trichinopoly and Nellore-Kistna districts. Senarmontite from Sarawak.

Part 4.—Geographical distribution of fossil organisms in India. Submerged forest on Bombay Island.

Vol. XII, 1879.

Part 1.—Annual report for 1878. Geology of Kashmir (third notice). Siwalik mammalia. Siwalik birds. Tour through Hangrang and Spiti. Mud eruption in Ramri Island (Arakan). Braunite, with Rhodonite, from Nagpur, Central Provinces. Palæontological notes from Satpura coal-basin. Coal importations into India.

Part 2.—Mohpani coal-field. Pyrolusite with Psilomelane at Gosalpur, Jabalpur district. Geological reconnaissance from Indus at Kushalgarh to Kurram at Thal on Afghan frontier. Geology of Upper Punjab.

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Part 4.—'Attock Slates' and their probable geological position. Marginal bone of undescribed tortoise, from Upper Siwaliks, near Nila, in Potwar, Punjab. Geology of North Arcot district. Road section from Murree to Abbottabad.

Vol. XIII, 1880.

Part 1.—Annual report for 1879. Geology of Upper Godavari basin in neighbourhood of Sironcha. Geology of Ladak and neighbouring districts. Teeth of fossil fishes from Ramri Island and Punjab. Fossil genera Nöggerathia, Stbg., Nöggerathiopsis, Fstm., and Rhiptozamites, Schmalh., in palæozoic and secondary rocks of Europe, Asia, and Australia. Fossil plants from Kattywar, Shekh Budin, and Sirgujah. Volanic foci of eruption in Konkan.

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VOL. XIV, 1881.

Part 1.—Annual report for 1880. Geology of part of Dardistan, Baltistan, and neighbouring districts. Siwalik carnivora. Siwalik group of Sub-Himalayan region. South Rewah Gondwana basin. Ferruginous beds associated with basaltic rocks of north-eastern Ulster, in relation to Indian laterite. Rajmahal plants. Travelled blocks of the Punjab. Appendix to 'Palæontological notes on lower trias of Himalayas.' Mammalian fossils from Perim Island.

Part 2.—Nahan-Siwalik unconformity in North-Western Himalaya. Gondwana vertebrates. Ossiferous beds of Hundes in Tibet. Mining records and mining record office of Great Britain; and Coal and Metalliferous Mines Act of 1872 (England). Cobaltite and danaite from Khetri mines, Rajputana; with remarks on Jaipurite (Syepoorite). Zinc-ore (Smithsonite and Blende) with barytes in Karnul district, Madras. Mud eruption in island of Cheduba.

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Part 4.—Unification of geological nomenclature and cartography. Geology of Arvali region, central and eastern. Native antimony obtained at Pulo Obin, near Singapore. Turgite from Juggiapett, Kistnah district, and zinc carbonate from Karnul, Madras. Section from Dalhousie to Pangi, *viâ* Sach Pass. South Rewah Gondwana basin. Submerged forest on Bombay Island.

VOL. XV, 1882.

Part 1.—Annual report for 1881. Geology of North-West Kashmir and Khagan. Gondwana labyrinthodonts. Siwalik and Jamna mammals. Geology of Dalhousie, North-West Himalaya. Palm leaves from (tertiary) Murree and Kasauli beds in India. Iridosmine from Noa-Dihing river, Upper Assam, and Platinum from Chutia Nagpur. On (1) copper mine near Yongri hill, Darjiling district; (2) arsenical pyrites in same neighbourhood; (3) kaolin at Darjiling. Analyses of coal and fire-clay from Makum coal-field, Upper Assam. Experiments on coal of Pind Dadun Khan, Salt-range, with reference to production of gas, made April 29th, 1881. Proceedings of International Congress of Bologna.

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Part 4 (out of print).—Gold-fields of Mysore. Borings for coal at Beddadanol, Godavari district, in 1874. Supposed occurrence of coal on Kistna.

VOL. XVI, 1883.

Part 1.—Annual report for 1882. Richthofenia, Kays (Anomia Lawrenciana, Koninck) Geology of South Travancore. Geology of Chamba. Basalts of Bombay.

Part 2.—Synopsis of fossil vertebrata of India. Bijori Labyrinthodont. Skuli of Hippotherium antilopinum. Iron ores, and subsidiary materials for manufacture of iron, in north-eastern part of Jabalpur district. Laterite and other manganese-ore occurring at Gosulpore, Jabalpur district. Umaria coal-field.

Part 3.—Microscopic structure of some Dalhousie rocks. Lavas of Aden. Probable occurrence of Siwalik strata in China and Japan. Mastodon angustidens in India. Traverse between Almora and Mussooree. Cretaceous coal-measures at Borsora, in Khasia Hills, near Laour, in Sylhet.

Part 4.—Palæontological notes from Daltonganj and Hutar coal-fields in Chota Nagpur. Altered basalts of Dalhousie region in North-Western Himalayas. Microscopic structure of some Sub-Himalayan rocks of tertiary age. Geology of Jaunsar and Lower Himalayas. Traverse through Eastern Khasia, Jaintia, and North Cachar Hills. Native lead from Maulmain and chromite from the Andaman Islands. Fiery eruption from one of mud volcanoes of Cheduba Island, Arakan. Irrigation from wells in North-Western Provinces and Oudh.

Vol. XVII, 1884.

Part 1.—Annual report for 1883. Smooth-water anchorages or mud-banks of Narrakal and Alleppy on Travancore coast. Billa Surgam and other caves in Kurnool district. Geology of Chuari and Sihunta parganas of Chamba. Lyttonia, Waagen, in Kuling series of Kashmir.

Part 2.—Earthquake of 31st December 1881 Microscopic structure of some Himalayan granites and gneissose granites. Choi coal exploration. Re-discovery of fossils in Siwalik beds. Mineral resources of the Andaman Islands in neighbourhood of Port Blair. Intertrappean beds in Deccan and Laramie group in Western North America.

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Part 4.—Geology of part of Gangasulan pargana of British Garhwal. Slates and schists imbedded in gneissose granite of North-West Himalayas. Geology of Takht-i-Suleiman. Smooth-water anchorages of Travancore coast. Auriferous sands of the Subansiri river. Pondicherry lignite, and phosphatic rocks at Musuri. Billa Surgam caves.

Vol. XVIII, 1885.

Part 1.—Annual report for 1884. Country between Singareni coal-field and Kistna river. Geological sketch of country between Singareni coal-field and Hyderabad. Coal and limestone in Doigrung river near Golaghat, Assam. Homotaxis, as illustrated from Indian formations. Afghan field notes.

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Part 4.—Geological work in Chhattisgarh division of Central Provinces. Bengal earthquake of 14th July 1885. Kashmir earthquake of 30th May 1885. Excavations in Billa Surgam caves. Nepaulite. Sabetmahet meteorite.

Vol. XIX, 1886.

Part 1.—Annual report for 1885. International Geological Congress of Berlin. Palæozoic Fossils in Olive group of Salt-range. Correlation of Indian and Australian coal-bearing beds. Afghan and Persian Field-notes. Section from Simla to Wangtu, and petrological character of Amphibolites and Quartz Diorites of Sutlej valley.

Part 2.—Geology of parts of Bellary and Anantapur districts. Geology of Upper Dehing basin in Singpho Hills. Microscopic characters of eruptive rocks from Central Himalayas. Mammalia of Karnul Caves. Prospects of finding coal in Western Rajputana. Olive group of Salt-range. Boulder-beds of Salt-range. Gondwana Homotaxis.

Part 3.—Geological sketch of Vizagapatam district. Madras. Geology of Northern Jesalmer. Microscopic structure of Malaini rocks of Arvali region. Malanjkhandi copper-ore in Balaghat district, C. P.

Part 4.—Petroleum in India. Petroleum exploration at Khátan. Boring in Chhattisgarh coal-fields. Field-notes from Afghanistan : No. 3, Turkistan. Fiery eruption from one of mud volcanoes of Cheduba Island, Arakan. Nammianthal aerolite. Analysis of gold dust from Meza valley, Upper Burma.

Vol. XX, 1887.

Part 1.—Annual report for 1886. Field-notes from Afghanistan: No. 4, from Turkistan to India. Physical geology of West British Garhwal; with notes on a route traversed through Jaunsar-Bawar and Tiri-Garhwal. Geology of Garo Hills. Indian image-stones. Soundings recently taken off Barren Island and Narcondam. Talchir boulder-beds. Analysis of Phosphatic Nodules from Salt-range, Punjab.

Part 2.—Fossil vertebrata of India. Echinoidea of cretaceous series of Lower Narbada Valley. Field-notes: No. 5—to accompany geological sketch map of Afghanistan and North-Eastern Khorassan. Microscopic structure of Rajmahal and Deccan traps. Dolerite of Chor. Identity of Olive series in east with speckled sandstone in west of Salt-range in Punjab.

Part 3.—Retirement of Mr. Medlicott. J. B. Mushketoff's Geology of Russian Turkistan. Crystalline and metamorphic rocks of Lower Himalaya, Garhwal, and Kumaun, Section I. Geology of Simla and Jutogh. 'Lalitpur' meteorite.

Part 4.—Points in Himalayan geology. Crystalline and metamorphic rocks of Lower Himalaya, Garhwal, and Kumaun, Section II. Iron industry of western portion of Raipur. Notes on Upper Burma. Boring exploration in Chhattisgarh coal-fields. (Second notice). Pressure Metamorphism, with reference to foliation of Himalayan Gneissose Granite. Papers on Himalayan Geology and Microscopic Petrology.

Vol. XXI, 1888.

Part 1.—Annual report for 1887. Crystalline and metamorphic rocks of Lower Himalaya, Garhwal, and Kumaun, Section III. Birds'-nest of Elephant Island, Mergui Archipelago. Exploration of Jessalmer, with a view to discovery of coal. Facetted pebble from boulder bed ('speckled sandstone') of Mount Chel in Salt-range, Punjab. Nodular stones obtained off Colombo.

Part 2.—Award of Wollaston Gold Medal, Geological Society of London, 1888. Dharwar System in South India. Igneous rocks of Raipur and Balaghat, Central Provinces. Sangar Marg and Mehowgale coal-fields, Kashmir.

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Part 4.—Indian fossil vertebrates. Geology of North-West Himalayas. Blown-sand rock sculpture. Nummulites in Zanskar. Mica traps from Barakar and Raniganj.

Vol. XXII, 1889.

Part 1.—Annual report for 1888. Dharwar System in South India. Wajra Karur diamonds, and M. Chaper's alleged discovery of diamonds in pegmatite. Generic position of so-called Plesiosaurus Indicus. Flexible sandstone or Itacolumite, its nature, mode of occurrence in India, and cause of its flexibility. Siwalik and Narbada Chelonia.

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Vol. XXIII, 1890.

Part 1.—Annual report for 1889. Lakadong coal-fields, Jaintia Hills. Pectoral and pelvic girdles and skull of Indian Dicynodonts. Vertebrate remains from Nagpur district (with description of fish-skull). Crystalline and metamorphic rocks of Lower Himalayas, Garhwál and Kumaun, Section IV. Vivalves of Olive-group, Salt-range. Mud-banks of Travancore coasts.

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VOL. XXIV, 1891.

Part 1.—Annual report for 1890. Geology of Salt-range of Punjab, with re-considered theory of Origin and Age of Salt-Mart. Graphite in decomposed Gneiss (Laterite) in Ceylon. Glaciers of Kabru, Pandim, etc. Salts of Sambhar Lake in Rajputana, and 'Reh' from Aligarh in North-Western Provinces. Analysis of Dolomite from Salt-range, Punjab.

Part 2.—Oil near Moghal Kot, in Sheráni country, Suleiman Hills. Mineral Oil from Suleiman Hills. Geology of Lushai Hills. Coal-fields in Northern Shan States. Reported Namsèka Ruby-mine in Mainglôn State. Tourmaline (Schorl) Mines in Mainglôn State. Salt-spring near Bawgyo, Thibaw State.

Part 3.—Boring in Daltongunj Coal-field, Palamow. Death of Dr. P. Martin Duncan. Pyroxenic varieties of Gneiss and Scapolite-bearing Rocks.

Part 4.—Mammalian Bones from Mongolia. Darjiling Coal Exploration. Geology and Mineral Resources of Sikkim. Rocks from the Salt-range, Punjab.

VOL. XXV, 1892.

Part 1.—Annual report for 1891. Geology of Thal Chotiáli and part of Mari country. Petrological Notes on Boulder-bed of Salt-range, Punjab. Sub-recent and Recent Deposits of valley plains of Quetta, Pishin, and Dasht-i-Bedaolat; with appendices on Chamans of Quetta; and Artesian water-supply of Quetta and Pishin.

Part 2 (out of print).—Geology of Saféd Kóh. Jherria Coal-field.

Part 3.—Locality of Indian Tscheffkinite. Geological Sketch of country north of Bhamo. Economic resources of Amber and Jade mines area in Upper Burma. Iron-ores and Iron Industries of Salem District. Riebeckite in India. Coal on Great Tenasserim River, Lower Burma.

Part 4.—Oil Springs at Moghal Kot in Shirani Hills. Mineral Oil from Suleiman Hills. New Amber-like Resin in Burma. Triassic Deposits of Salt-range.

VOL. XXVI, 1893.

Part 1.—Annual report for 1892. Central Himalayas. Jadeite in Upper Burma. Burmite, new Fossil Resin from Upper Burma. Prospecting Operations, Mergui District, 1891-92.

Part 2.—Earthquake in Baluchistan on 20th December 1892. Burmite, new amber-like fossil resin from Upper Burma. Alluvial deposits and Subterranean water-supply of Rangoon.

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Part 4.—Geology of country between Chappar Rift and Harnai in Baluchistán. Geology of part of Tenasserim Valley with special reference to Tendau-Kamapying Coal-field. Magnetite containing Manganese and Alumina. Hislopite.

VOL. XXVII, 1894.

Part 1.—Annual report for 1893. Bhaganwala Coal-field, Salt-range, Punjab.

Part 2.—Petroleum from Burma. Singareni Coal-field, Hyderabad (Deccan). Gohna Landslip, Garhwal.

Part 3.—Cambrian Formation of Eastern Salt-range. Giridih (Karharbari) Coal-fields. Chipped (?) Flints in Upper Miocene of Burma. Velates Schmideliana, Chemn., and Provelates grandis, Sow. sp., in Tertiary Formation of India and Burma.

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VOL. XXVIII, 1895.

Part 1.—Annual report for 1894. Cretaceous Formation of Pondicherry. Early allusion to Barren Island. Bibliography of Barren Island and Narcondam from 1884 to 1894.

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Part 4.—Igneous Rocks of Giridih (Kurhurbaree) Coal-field and their Contact Effects. Vindhyan system south of Sone and their relation to so-called Lower Vindhyans. Lower Vindhyan area of Sone Valley. Tertiary system in Burma.

VOL. XXIX, 1896.

Part 1.—Annual report for 1895. Acicular inclusions in Indian Garnets. Origin and Growth of Garnets and of their Micropegmatitic intergrowths in Pyroxenic rocks.

Part 2.—Ultra-basic rocks and derived minerals of Chalk (Magnesite) hills, and other localities near Salem, Madras. Corundum localities in Salem and Coimbatore districts, Madras. Corundum and Kyanite in Manbhum district, Bengal. Ancient Geography of "Gondwanaland." Notes.

Part 3.—Igneous Rocks from the Tochi Valley. Notes.

Part 4.—Steatite mines, Minbu district, Burma. Lower Vindhyan (Sub-Kaimur) area of Sone Valley, Rewah. Notes.

VOL. XXX, 1897.

Part 1.—Annual report for 1896. Norite and associated Basic Dykes and Lava-flows in Southern India. Genus Vertebraria. On Glossopteris and Vertebraria.

Part 2.—Cretaceous Deposits of Pondicherri. Notes.

Part 3.—Flow structure in igneous dyke. Olivine-norite dykes at Coonoor. Excavations for corundum near Palakod, Salem District. Occurrence of coal at Palana in Bikanir. Geological specimens collected by Afghan-Baluch Boundary Commission of 1896.

Part 4.—Nemalite from Afghanistan. Quartz-barytes rock in Salem District, Madras Presidency. Worn femur of Hippopotamus irravadicus, Caut. and Falc., from Lower Pliocene of Burma. Supposed coal at Jaintia, Baxa Duars. Percussion Figures on micas. Notes.

VOL. XXXI, 1904.

Part 1 (out of print).—Prefatory Notice. Copper-ore near Komai, Darjeeling district. Zewan beds in Vihi district, Kashmir. Coal deposits of Isa Khel, Mianwali district, Punjab. Um-Rileng coal-beds, Assam. Sapphirine-bearing rock from Vizagapatam district. Miscellaneous Notes. Assays.

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Part 4 (out of print).—Geology of Upper Assam. Auriferous Occurrences of Assam. Curious occurrence of Scapolite from Madras Presidency. Miscellaneous Notes. Index.

VOL. XXXII, 1905.

Part 1 (out of print).—Review of Mineral Production of India during 1898—1903.

Part 2 (out of print).—General report, April 1903 to December 1904. Geology of Provinces of Tsang and Ü in Tibet. Bauxite in India. Miscellaneous Notes.

Part 3 (out of print).—Anthracolithic Fauna from Subansri Gorge, Assam. Elephas Antiquus (Namadicus) in Godavari Alluvium. Triassic Fauna of Tropites-Limestone of Byans. Amblygonite in Kashmir. Miscellaneous Notes.

Part 4.—Obituary notices of H. B. Medlicott and W. T. Blanford. Kangra Earthquake of 4th April 1905. Index to Volume XXXII.

VOL. XXXIII, 1906.

Part 1 (out of print).—Mineral Production of India during 1904. Pleistocene Movement in Indian Peninsula. Recent Changes in Course of Nam-tu River, Northern Shan States. Natural Bridge in Gokteik Gorge. Geology and Mineral Resources of Narnaul District (Patiala State). Miscellaneous Notes.

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Part 4 (out of print).—Composition and Quality of Indian Coals. Classification of the Vindhyan System. Geology of State of Panna with reference to the Diamond bearing Deposits. Index to Volume XXXIII.

VOL. XXXIV, 1906.

Part 1.—Fossils from Halorites Limestone of Bambanag Cliff, Kumaon. Upper-Triassic Fauna from Pishin District, Baluchistan. Geology of portion of Bhutan. Coal Occurrences in Foot-hills of Bhutan. Dandli Coal-field : Coal outcrops in Kotli Tehsil of Jammu State. Miscellaneous Notes.

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Part 3.—Explosion Craters in Lower Chindwin district, Burma. Lavas of Pavagad Hill. Gibbsite with Manganese-ore from Talevadi, Belgaum district, and Gibbsite from Bhekowli, Satara District. Classification of Tertiary System in Sind with reference to Zonal distribution of Eocene Echinoidea.

Part 4 (out of print).—Jaipur and Nazira Coal-fields, Upper Assam. Makum Coal-field between Tirap and Namdang Streams. Kabat Anticline, near Seiktein, Myingyan district, Upper Burma. Asymmetry of Yenangyat-Singu Anticline, Upper Burma. Northern part of Gwegyo Anticline, Myingyan District, Upper Burma. Breynia Multituberculata, from Nari of Baluchistan and Sind. Index to Volume XXXIV.

VOL. XXXV, 1907.

Part 1.—General report for 1906. Orthophragmina and Lepidocyclina in Nummulitic Series. Meteoric Shower of 22nd October 1903 at Dokáchi and neighbourhood, Dacca District.

Part 2.—Indian Aerolites. Brine-wells at Bawgyo, Northern Shan States. Gold-bearing Deposits of Loi Twang, Shan States. Physa Prinsepii in Maestrichtian strata of Baluchistan. Miscellaneous Notes.

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Part 4.—Preliminary survey of certain Glaciers in North-West Himalaya. B.—Notes on certain Glaciers in Lahaul. C.—Notes on certain Glaciers in Kumaon. Index to Volume XXXV.

VOL. XXXVI, 1907-08.

Part 1.—Petrological Study of Rocks from hill tracts, Vizagapatam district, Madras Presidency. Nepheline Syenites from hill tracts, Vizagapatam district, Madras Presidency. Stratigraphical Position of Gangamopteris Beds of Kashmir. Volcanic outburst of Late Tertiary Age in South Hsenwi, N. Shan States. New suidæ from Bugti Hills, Baluchistan. Permo-Carboniferous Plants from Kashmir.

Part 2.—Mineral Production of India during 1906. Ammonites of Bagh Beds. Miscellaneous Notes.

Part 3.—Marine fossils in Yenangyaung oil-field, Upper Burma. Fresh-water shells of genus Batissa in Yenangyaung oil-field, Upper Burma. New Species of Dendrophyllia from Upper Miocene of Burma. Structure and age of Taungtha hills, Myingyan district, Upper Burma. Fossils from Sedimentary rocks of Oman (Arabia). Rubies in Kachin hills, Upper Burma. Cretaceous Orbitoides of India. Two Calcutta Earthquakes of 1906. Miscellaneous Notes.

Part 4.—Pseudo-Fucoids from Pab sandstones at Fort Munro, and from Vindhyan series. Jadeite in Kachin Hills, Upper Burma. Wetchok-Yedwet Pegu outcrop, Magwe district, Upper Burma. Group of manganates, comprising Hollandite, Psilomelane and Coronadite. Occurrence of Wolfram in Nagpur district, Central Provinces. Miscellaneous Notes. Index to Volume XXXVI.

VOL. XXXVII, 1908-09.

Part 1.—General report for 1907. Mineral Production of India during 1907. Striated boulders in the Blaini formation.

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VOL. XIV, 1881.

Part 1.—Annual report for 1880. Geology of part of Dardistan, Baltistan, and neighbouring districts. Siwalik carnivora. Siwalik group of Sub-Himalayan region. South Rewah Gondwana basin. Ferruginous beds associated with basaltic rocks of north-eastern Ulster, in relation to Indian laterite. Rajmahal plants. Travelled blocks of the Punjab. Appendix to 'Palæontological notes on lower trias of Himalayas.' Mammalian fossils from Perim Island.

Part 2.—Nahan-Siwalik unconformity in North-Western Himalaya. Gondwana vertebrates. Ossiferous beds of Hundes in Tibet. Mining records and mining record office of Great Britain; and Coal and Metalliferous Mines Act of 1872 (England). Cobaltite and danaite from Khetri mines, Rajputana; with remarks on Jaipurite (Syepoorite). Zinc-ore (Smithsonite and Blende) with barytes in Karnul district, Madras. Mud eruption in island of Cheduba.

Part 3.—Artesian borings in India. Oligoclase granite at Wangtu on Sutlej, North-West Himalayas. Fish-palate from Siwaliks. Palæontological notes from Hazaribagh and Lohardagga districts. Fossil carnivora from Siwalik hills.

Part 4.—Unification of geological nomenclature and cartography. Geology of Arvali region, central and eastern. Native antimony obtained at Pulo Obin, near Singapore. Turgite from Juggiapett, Kistnah district, and zinc carbonate from Karnul, Madras. Section from Dalhousie to Pangi, *viâ* Sach Pass. South Rewah Gondwana basin. Submerged forest on Bombay Island.

VOL. XV, 1882.

Part 1.—Annual report for 1881. Geology of North-West Kashmir and Khagan. Gondwana labyrinthodonts. Siwalik and Jamna mammals. Geology of Dalhousie, North-West Himalaya. Palm leaves from (tertiary) Murree and Kasauli beds in India. Iridosmine from Noa-Dihing river, Upper Assam, and Platinum from Chutia Nagpur. On (1) copper mine near Yongri hill, Darjiling district; (2) arsenical pyrites in same neighbourhood; (3) kaolin at Darjiling. Analyses of coal and fire-clay from Makum coal-field, Upper Assam. Experiments on coal of Pind Dadun Khan, Salt-range, with reference to production of gas, made April 29th, 1881. Proceedings of International Congress of Bologna.

Part 2.—Geology of Travancore State. Warkilli beds and reported associated deposits at Quilon, in Travancore. Siwalik and Narbada fossils. Coal-bearing rocks of Upper Rer and Mand rivers in Western Chutia Nagpur. Pench river coal-field in Chhindwara district, Central Provinces. Borings for coal at Engsein, British Burma. Sapphires in North-Western Himalaya. Eruption of mud volcanoes in Cheduba.

Part 3.—Coal of Mach (Much) in Bolan Pass, and of Sharigh on Harnai route between Sibi and Quetta. Crystals of stilbite from Western Ghats, Bombay. Traps of Darang and Mandi in North-Western Himalayas. Connexion between Hazara and Kashmir series. Umaria coal-field (South Rewah Gondwana basin). Daranggiri coal-field, Garo Hills, Assam. Coal in Myanoung division, Henzada district.

Part 4 (out of print).—Gold-fields of Mysore. Borings for coal at Beddadanol, Godavari district, in 1874. Supposed occurrence of coal on Kistna.

VOL. XVI, 1883.

Part 1.—Annual report for 1882. Richthofenia, Kays (Anomia Lawrenciana, Koninck). Geology of South Travancore. Geology of Chamba. Basalts of Bombay.

Part 2.—Synopsis of fossil vertebrata of India. Bijori Labyrinthodont. Skuli of Hippotherium antilopinum. Iron ores, and subsidiary materials for manufacture of iron, in north-eastern part of Jabalpur district. Laterite and other manganese-ore occurring at Gosulpore, Jabalpur district. Umaria coal-field.

Part 3.—Microscopic structure of some Dalhousie rocks. Lavas of Aden. Probable occurrence of Siwalik strata in China and Japan. Mastodon angustidens in India. Traverse between Almora and Mussooree. Cretaceous coal-measures at Borsora, in Khasia Hills, near Laour, in Sylhet.

Part 4.—Palæontological notes from Daltonganj and Hutar coal-fields in Chota Nagpur. Altered basalts of Dalhousie region in North-Western Himalayas. Microscopic structure of some Sub-Himalayan rocks of tertiary age. Geology of Jaunsar and Lower Himalayas. Traverse through Eastern Khasia, Jaintia, and North Cachar Hills. Native lead from Maulmain and chromite from the Andaman Islands. Fiery eruption from one of mud volcanoes of Cheduba Island, Arakan. Irrigation from wells in North-Western Provinces and Oudh.

Vol. XVII, 1884.

Part 1.—Annual report for 1883. Smooth-water anchorages or mud-banks of Narrakal and Alleppy on Travancore coast. Billa Surgam and other caves in Kurnool district. Geology of Chuari and Sihunta parganas of Chamba. Lyttonia, Waagen, in Kuling series of Kashmir.

Part 2.—Earthquake of 31st December 1881 Microscopic structure of some Himalayan granites and gneissose granites. Choi coal exploration. Re-discovery of fossils in Siwalik beds. Mineral resources of the Andaman Islands in neighbourhood of Port Blair. Intertrappean beds in Deccan and Laramie group in Western North America.

Part 3 (out of print).—Microscopic structure of some Arvali rocks. Section along Indus from Peshawar Valley to Salt-range. Sites for boring in Raigarh-Hingir coal-field (first notice). Lignite near Raipore, Central Provinces. Turquoise mines of Nishâpûr, Khorassan. Fiery eruption from Minbyin mud volcano of Cheduba Island, Arakan. Langrin coal-field, South-Western Khasia Hills. Umaria coal-field.

Part 4.—Geology of part of Gangasulan pargana of British Garhwal. Slates and schists imbedded in gneissose granite of North-West Himalayas. Geology of Takht-i-Suleiman. Smooth-water anchorages of Travancore coast. Auriferous sands of the Subansiri river. Pondicherry lignite, and phosphatic rocks at Musuri. Billa Surgam caves.

Vol. XVIII, 1885.

Part 1.—Annual report for 1884. Country between Singareni coal-field and Kistna river. Geological sketch of country between Singareni coal-field and Hyderabad. Coal and limestone in Doigrung river near Golaghat, Assam. Homotaxis, as illustrated from Indian formations. Afghan field notes.

Part 2.—Fossiliferous series in Lower Himalaya, Garhwal. Age of Mandhali series in Lower Himalaya. Siwalik camel (Camelus Antiquus, nobis ex Falc. and Caut. MS.). Geology of Chamba. Probability of obtaining water by means of artesian wells in plains of Upper India. Artesian sources in plains of Upper India. Geology of Aka Hills. Alleged tendency of Arakan mud volcanoes to burst into eruption most frequently during rains. Analyses of phosphatic nodules and rock from Mussooree.

Part 3.—Geology of Andaman Islands. Third species of Merycopotamus. Percolation as affected by current. Pirthalla and Chandpur meteorites. Oil-wells and coal in Thayetmyo district, British Burma. Antimony deposits in Maulman district. Kashmir earthquake of 30th May 1885. Bengal earthquake of 14th July 1885.

Part 4.—Geological work in Chhattisgarh division of Central Provinces. Bengal earthquake of 14th July 1885. Kashmir earthquake of 30th May 1885. Excavations in Billa Surgam caves. Nepaulite. Sabetmahet meteorite.

Vol. XIX, 1886.

Part 1.—Annual report for 1885. International Geological Congress of Berlin. Palæozoic Fossils in Olive group of Salt-range. Correlation of Indian and Australian coal-bearing beds. Afghan and Persian Field-notes. Section from Simla to Wangtu, and petrological character of Amphibolites and Quartz Diorites of Sutlej valley.

Part 2.—Geology of parts of Bellary and Anantapur districts. Geology of Upper Dehing basin in Singpho Hills. Microscopic characters of eruptive rocks from Central Himalayas. Mammalia of Karnul Caves. Prospects of finding coal in Western Rajputana. Olive group of Salt-range. Boulder-beds of Salt-range. Gondwana Homotaxis.

Part 3.—Geological sketch of Vizagapatam district, Madras. Geology of Northern Jesalmer. Microscopic structure of Malaini rocks of Arvali region. Malanjkhandi copper-ore in Balaghat district, C. P.

Part 4.—Petroleum in India. Petrōleum exploration at Khâtan. Boring in Chhattisgarh coal-fields. Field-notes from Afghanistan : No. 3, Turkistan. Fiery eruption from one of mud volcanoes of Cheduba Island. Arakan. Nammianthal aerolite. Analysis of gold dust from Meza valley, Upper Burma.

Vol. XX, 1887.

Part 1.—Annual report for 1886. Field-notes from Afghanistan : No. 4, from Turkistan to India. Physical geology of West British Garhwal; with notes on a route traversed through Jaunsar-Bawar and Tiri-Garhwal. Geology of Garo Hills. Indian millstones. Soundings recently taken off Barren Island and Narcondam. Talchir boulder-beds. Analysis of Phosphatic Nodules from Salt-range, Punjab.

Part 2.—Fossil vertebrata of India. Echinoidea of cretaceous series of Lower Narbada Valley. Field-notes : No. 5—to accompany geological sketch map of Afghanistan and North-Eastern Khorassan. Microscopic structure of Rajmahal and Deccan traps. Dolerite of Chor. Identity of Olive series in east with speckled sandstone in west of Salt-range in Punjab.

Part 3.—Retirement of Mr. Medlicott. J. B. Mushketoff's Geology of Russian Turkistan. Crystalline and metamorphic rocks of Lower Himalaya, Garhwal, and Kumaun, Section I. Geology of Simla and Jutogh. 'Lalitpur' meteorite.

Part 4.—Points in Himalayan geology. Crystalline and metamorphic rocks of Lower Himalaya, Garhwal, and Kumaun, Section II. Iron industry of western portion of Raipur. Notes on Upper Burma. Boring exploration in Chhattisgarh coal-fields. (Second notice). Pressure Metamorphism, with reference to foliation of Himalayan Gneissose Granite. Papers on Himalayan Geology and Microscopic Petrology.

Vol. XXI, 1888.

Part 1.—Annual report for 1887. Crystalline and metamorphic rocks of Lower Himalaya, Garhwal, and Kumaun, Section III. Birds'-nest of Elephant Island, Mergui Archipelago. Exploration of Jessalmer, with a view to discovery of coal. Facetted pebble from boulder bed ('speckled sandstone') of Mount Chel in Salt-range, Punjab. Nodular stones obtained off Colombo.

Part 2.—Award of Wollaston Gold Medal, Geological Society of London, 1888. Dharwar System in South India. Igneous rocks of Raipur and Balaghat, Central Provinces. Sangar Marg and Mehowgale coal-fields, Kashmir.

Part 3.—Manganese Iron and Manganese Ores of Jabalpur. 'The Carboniferous Glacial Period.' Pre-tertiary sedimentary formations of Simla region of Lower Himalayas.

Part 4.—Indian fossil vertebrates. Geology of North-West Himalayas. Blown-sand rock sculpture. Nummulites in Zanskar. Mica traps from Barakar and Raniganj.

Vol. XXII, 1889.

Part 1.—Annual report for 1888. Dharwar System in South India. Wajra Karur diamonds, and M. Chaper's alleged discovery of diamonds in pegmatite. Generic position of so-called Plesiosaurus Indicus. Flexible sandstone or Itacolumite, its nature, mode of occurrence in India, and cause of its flexibility. Siwalik and Narbada Chelonia.

Part 2.—Indian Steatite. Distorted pebbles in Siwalik conglomerate. 'Carboniferous Glacial Period.' Oil-fields of Twingoung and Beme, Burma. Gypsum of Nehal Nadi, Kumaun. Materials for pottery in neighbourhood of Jabalpur and Umaria.

Part 3.—Coal outcrops in Sharigh Valley, Baluchistan. Trilobites in Neobolus beds of Salt-range. Geological notes. Cherra Poonjee coal-field, in Khasia Hills. Cobaltiferous Matt from Nepál. President of Geological Society of London on International Geological Congress of 1888. Tin-mining in Mergui district.

Part 4.—Land-tortoises of Siwaliks. Pelvis of a ruminant from Siwaliks. Assays from Sambhar Salt-Lake in Rajputana. Manganiferous iron and Manganese Ores of Jabalpur. Palagonite-bearing traps of Rájmahál hills and Deccan. Tin-smelting in Malay Peninsula. Provisional Index of Local Distribution of Important Minerals, Miscellaneous Minerals, Gem Stones and Quarry Stones in Indian Empire. Part 1.

Vol. XXIII, 1890.

Part 1.—Annual report for 1889. Lakadong coal-fields, Jaintia Hills. Pectoral and pelvic girdles and skull of Indian Dicynodonts. Vertebrate remains from Nagpur district (with description of fish-skull). Crystalline and metamorphic rocks of Lower Himalayas, Garhwál and Kumaun, Section IV. Vivalves of Olive-group, Salt-range. Mud-banks of Travancore coasts.

Part 2.—Petroleum explorations in Harnai district, Baluchistan. Sapphire Mines of Kashmir. Supposed Matrix of Diamond at Wajra Karur, Madras. Sonapet Goldfield. Field notes from Shan Hills (Upper Burma). New species of Syringosphæridæ.

Part 3.—Geology and Economic Resources of Country adjoining Sind-Pishin Railway between Sharigh and Spintangi, and of country between it and Khattan. Journey through India in 1888-89, by Dr. Johannes Walther. Coal-fields of Lairungao, Maosandram, and Mao-belar-kar, in the Khasi Hills. Indian Steatite. Provisional Index of Local Distribution of Important Minerals, Miscellaneous Minerals, Gem Stones, and Quarry Stones in Indian Empire.

Part 4.—Geological sketch of Naini Tal; with remarks on natural conditions governing mountain slopes. Fossil Indian Bird Bones. Darjiling Coal between Lisu and Ramthi rivers. Basic Eruptive Rocks of Kadapah Area. Deep-Boring at Lucknow. Coal Seam of Dore Ravine, Hazara.

Vol. XXIV, 1891.

Part 1.—Annual report for 1890. Geology of Salt-range of Punjab, with re-considered theory of Origin and Age of Salt-Mart. Graphite in decomposed Gneiss (Laterite) in Ceylon. Glaciers of Kabru, Pandim, etc. Salts of Sambhar Lake in Rajputana, and 'Reh' from Aligarh in North-Western Provinces. Analysis of Dolomite from Salt-range, Punjab.

Part 2.—Oil near Moghal Kot, in Sheráni country, Suleiman Hills. Mineral Oil from Suleiman Hills. Geology of Lushai Hills. Coal-fields in Northern Shan States. Reported Namsèka Ruby-mine in Mainglôn State. Tourmaline (Schorl) Mines in Mainglôn State. Salt-spring near Bawgyo, Thibaw State.

Part 3.—Boring in Daltongunj Coal-field, Palamow. Death of Dr. P. Martin Duncan. Pyroxenic varieties of Gneiss and Scapolite-bearing Rocks.

Part 4.—Mammalian Bones from Mongolia. Darjiling Coal Exploration. Geology and Mineral Resources of Sikkim. Rocks from the Salt-range, Punjab.

Vol. XXV, 1892.

Part 1.—Annual report for 1891. Geology of Thal Chotiáli and part of Mari country. Petrological Notes on Boulder-bed of Salt-range, Punjab. Sub-recent and Recent Deposits of valley plains of Quetta, Pishin, and Dasht-i-Bedaolat; with appendices on Chamans of Quetta; and Artesian water-supply of Quetta and Pishin.

Part 2 (out of print).—Geology of Saféd Kóh. Jherria Coal-field.

Part 3.—Locality of Indian Tscheffkinite. Geological Sketch of country north of Bhamo. Economic resources of Amber and Jade mines area in Upper Burma. Iron-ores and Iron Industries of Salem District. Riebeckite in India. Coal on Great Tenasserim River, Lower Burma.

Part 4.—Oil Springs at Moghal Kot in Shirani Hills. Mineral Oil from Suleiman Hills. New Amber-like Resin in Burma. Triassic Deposits of Salt-range.

Vol. XXVI, 1893.

Part 1.—Annual report for 1892. Central Himalayas. Jadeite in Upper Burma. Burmite, new Fossil Resin from Upper Burma. Prospecting Operations, Mergui District, 1891-92.

Part 2.—Earthquake in Baluchistan on 20th December 1892. Burmite, new amber-like fossil resin from Upper Burma. Alluvial deposits and Subterranean water-supply of Rangoon.

Part 3.—Geology of Sherani Hills. Carboniferous Fossils from Tenasserim. Boring at Chandernagore. Granite in Tavoy and Mergui.

Part 4.—Geology of country between Chappar Rift and Harnai in Baluchistán. Geology of part of Tenasserim Valley with special reference to Tendau-Kamapying Coal-field. Magnetite containing Manganese and Alumina. Hislopite.

Vol. XXVII, 1894.

Part 1.—Annual report for 1893. Bhaganwala Coal-field, Salt-range, Punjab.

Part 2.—Petroleum from Burma. Singareni Coal-field, Hyderabad (Deccan). Gohna Landslip, Garhwal.

Part 3.—Cambrian Formation of Eastern Salt-range. Giridih (Karharbari) Coal-fields. Chipped (?) Flints in Upper Miocene of Burma. Velates Schmideliana, Chemn., and Provelates grandis, Sow. sp., in Tertiary Formation of India and Burma.

Part 4.—Geology of Wuntho in Upper Burma. Echinoids from Upper Cretaceous System of Baluchistán. Highly Phosphatic Mica Peridotites intrusive in Lower Gondwana Rocks of Bengal. Mica-Hypersthene-Hornblende-Peridotite in Bengal.

Vol. XXVIII, 1895.

Part 1.—Annual report for 1894. Cretaceous Formation of Pondicherry. Early allusion to Barren Island. Bibliography of Barren Island and Narcondam from 1884 to 1894.

Part 2.—Cretaceous Rocks of Southern India and geographical conditions during later cretaceous times. Experimental Boring for Petroleum at Sukkur from October 1893 to March 1895. Tertiary system in Burma.

Part 3.—Jadeite and other rocks, from Tammaw in Upper Burma. Geology of Tochi Valley. Lower Gondwanas in Argentina.

Part 4.—Igneous Rocks of Giridih (Kurhurbaree) Coal-field and their Contact Effects. Vindhyan system south of Sone and their relation to so-called Lower Vindhyans. Lower Vindhyan area of Sone Valley. Tertiary system in Burma.

VOL. XXIX, 1896.

Part 1.—Annual report for 1895. Acicular inclusions in Indian Garnets. Origin and Growth of Garnets and of their Micropegmatitic intergrowths in Pyroxenic rocks.

Part 2.—Ultra-basic rocks and derived minerals of Chalk (Magnesite) hills, and other localities near Salem, Madras. Corundum localities in Salem and Coimbatore districts, Madras. Corundum and Kyanite in Manbhum district, Bengal. Ancient Geography of "Gondwanaland." Notes.

Part 3.—Igneous Rocks from the Tochi Valley. Notes.

Part 4.—Steatite mines, Minbu district, Burma. Lower Vindhyan (Sub-Kaimur) area of Sone Valley, Rewah. Notes.

VOL. XXX, 1897.

Part 1.—Annual report for 1896. Norite and associated Basic Dykes and Lava-flows in Southern India. Genus Vertebraria. On Glossopteris and Vertebraria.

Part 2.—Cretaceous Deposits of Pondicherri. Notes.

Part 3.—Flow structure in igneous dyke. Olivine-norite dykes at Coonoor. Excavations for corundum near Palakod, Salem District. Occurrence of coal at Palana in Bikanir. Geological specimens collected by Afghan-Baluch Boundary Commission of 1896.

Part 4.—Nemalite from Afghanistan. Quartz-barytes rock in Salem District, Madras Presidency. Worn femur of Hippopotamus irravadicus, Caut. and Falc., from Lower Pliocene of Burma. Supposed coal at Jaintia, Baxa Duars. Percussion Figures on micas. Notes.

VOL. XXXI, 1904.

Part 1 (out of print).—Prefatory Notice. Copper-ore near Komai, Darjeeling district. Zewan beds in Vihi district, Kashmir. Coal deposits of Isa Khel, Mianwali district, Punjab. Um-Rileng coal-beds, Assam. Sapphirine-bearing rock from Vizagapatam district. Miscellaneous Notes. Assays.

Part 2 (out of print).—Lt.-Genl. C. A. McMahon. Cyclobus Haydeni Diener. Auriferous Occurrences of Chota Nagpur, Bengal. On the feasibility of introducing modern methods of Coke-making at East Indian Railway Collieries, with supplementary note by Director, Geological Survey of India. Miscellaneous Notes.

Part 3 (out of print).—Upper Palæozoic formations of Eurasia. Glaciation and History of Sind Valley. Halorites in Trias of Baluchistan. Geology and Mineral Resources of Mayurbhanj. Miscellaneous Notes.

Part 4 (out of print).—Geology of Upper Assam. Auriferous Occurrences of Assam. Curious occurrence of Scapolite from Madras Presidency. Miscellaneous Notes. Index.

VOL. XXXII, 1905.

Part 1 (out of print).—Review of Mineral Production of India during 1898—1903.

Part 2 (out of print).—General report, April 1903 to December 1904. Geology of Provinces of Tsang and Ü in Tibet. Bauxite in India. Miscellaneous Notes.

Part 3 (out of print).—Anthracolithic Fauna from Subansri Gorge, Assam. Elephas Antiquus (Namadicus) in Godavari Alluvium. Triassic Fauna of Tropites-Limestone of Byans. Amblygonite in Kashmir. Miscellaneous Notes.

Part 4.—Obituary notices of H. B. Medlicott and W. T. Blanford. Kangra Earthquake of 4th April 1905. Index to Volume XXXII.

VOL. XXXIII, 1906.

Part 1 (out of print).—Mineral Production of India during 1904. Pleistocene Movement in Indian Peninsula. Recent Changes in Course of Nam-tu River, Northern Shan States. Natural Bridge in Gokteik Gorge. Geology and Mineral Resources of Narnaul District (Patiala State). Miscellaneous Notes.

Part 2 (out of print).—General report for 1905. Lashio Coal-field, Northern Shan States. Namma, Mansang and Man-se-le Coal-fields, Northern Shan States, Burma Miscellaneous Notes.

Part 3.—Petrology and Manganese-Ore Deposits of Sausar Tahsil, Chhindwara district, Central Provinces. Geology of parts of valley of Kanhan River in Nagpur and Chhindwara districts, Central Provinces. Manganite from Sandur Hills. Miscellaneous Notes.

Part 4 (out of print).—Composition and Quality of Indian Coals. Classification of the Vindhyan System. Geology of State of Panna with reference to the Diamond bearing Deposits. Index to Volume XXXIII.

VOL. XXXIV, 1906.

Part 1.—Fossils from Halorites Limestone of Bambanag Cliff, Kumaon. Upper-Triassic Fauna from Pishin District, Baluchistan. Geology of portion of Bhutan. Coal Occurrences in Foot-hills of Bhutan. Dandli Coal-field : Coal outcrops in Kotli Tehsil of Jammu State. Miscellaneous Notes.

Part 2.—Mineral Production of India during 1905. Nummulites Douvillei, with remarks on Zonal Distribution of Indian Nummulites. Auriferous Tracts in Southern India. Abandonment of Collieries at Warora, Central Provinces. Miscellaneous Notes.

Part 3.—Explosion Craters in Lower Chindwin district, Burma. Lavas of Pavagad Hill. Gibbsite with Manganese-ore from Talevadi, Belgaum district, and Gibbsite from Bhekowli, Satara District. Classification of Tertiary System in Sind with reference to Zonal distribution of Eocene Echinoidea.

Part 4 (out of print).—Jaipur and Nazira Coal-fields, Upper Assam. Makum Coal-field between Tirap and Namdang Streams. Kabat Anticline, near Seiktein, Myingyan district, Upper Burma. Asymmetry of Yenangyat-Singu Anticline, Upper Burma. Northern part of Gwegyo Anticline, Myingyan District, Upper Burma. Breynia Multituberculata, from Nari of Baluchistan and Sind. Index to Volume XXXIV.

VOL. XXXV, 1907.

Part 1.—General report for 1906. Orthophragmina and Lepidocyclina in Nummulitic Series. Meteoric Shower of 22nd October 1903 at Dokáchi and neighbourhood, Dacca District.

Part 2.—Indian Aerolites. Brine-wells at Bawgyo, Northern Shan States. Gold-bearing Deposits of Loi Twang, Shan States. Physa Prinsepii in Maestrichtian strata of Baluchistan. Miscellaneous Notes.

Part 3.—Preliminary survey of certain Glaciers in North-West Himalaya. A.—Notes on certain Glaciers in North-West Kashmir.

Part 4.—Preliminary survey of certain Glaciers in North-West Himalaya. B.—Notes on certain Glaciers in Lahaul. C.—Notes on certain Glaciers in Kumaon. Index to Volume XXXV.

VOL. XXXVI, 1907-08.

Part 1.—Petrological Study of Rocks from hill tracts, Vizagapatam district, Madras Presidency. Nepheline Syenites from hill tracts, Vizagapatam district, Madras Presidency. Stratigraphical Position of Gangamopteris Beds of Kashmir. Volcanic outburst of Late Tertiary Age in South Hsenwi, N. Shan States. New suidæ from Bugti Hills, Baluchistan. Permo-Carboniferous Plants from Kashmir.

Part 2.—Mineral Production of India during 1906. Ammonites of Bagh Beds. Miscellaneous Notes.

Part 3.—Marine fossils in Yenangyaung oil-field, Upper Burma. Fresh-water shells of genus Batissa in Yenangyaung oil-field, Upper Burma. New Species of Dendrophyllia from Upper Miocene of Burma. Structure and age of Taungtha hills, Myingyan district, Upper Burma. Fossils from Sedimentary rocks of Oman (Arabia). Rubies in Kachin hills, Upper Burma. Cretaceous Orbitoides of India. Two Calcutta Earthquakes of 1906. Miscellaneous Notes.

Part 4.—Pseudo-Fucoids from Pab sandstones at Fort Munro, and from Vindhyan series. Jadeite in Kachin Hills, Upper Burma. Wetchok-Yedwet Pegu outcrop. Magwe district, Upper Burma. Group of manganates, comprising Hollandite, Psilomelane and Coronadite. Occurrence of Wolfram in Nagpur district, Central Provinces. Miscellaneous Notes. Index to Volume XXXVI.

VOL. XXXVII, 1908-09.

Part 1.—General report for 1907. Mineral Production of India during 1907. Striated boulders in the Blaini formation.

Part 2.—Tertiary and Post-Tertiary Freshwater Deposits of Baluchistan and Sind. Geology and Minerals of Rajpipla. Suitability of Rajmahal sands for glass-making. Vredenburgite, Sitaparite and Juddite. Laterites from the Central Provinces. Miscellaneous notes.

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THE GEOLOGICAL SURVEY OF INDIA.

VOLUME XXXVII.

THE MANGANESE-ORE DEPOSITS OF INDIA, *by* L. LEIGH FERMOR, A.R.S.M., B.Sc. (LONDON), F.G.S., *Assistant Superintendent, Geological Survey of India.*

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Part 1 (out of print).—Annual report for 1873. Hill ranges between Indus valley in Ladak and Shah-i-Dula on frontier of Yarkand territory. Iron ores of Kumaon. Raw materials for iron-smelting in Raniganj field. Elastic sandstone, or so-called Itacolumyte. Geological notes on part of Northern Hazaribagh.

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Part 3.—Geological observations made on a visit to Chaderkul, Thian Shan range. Former extension of glaciers within Kangra district. Building and ornamental stones of India. Materials for iron manufacture in Raniganj coal-field. Manganese-ore in Wardha coal-field.

Part 4 (out of print).—Auriferous rocks of Dhambal hills, Dharwar district. Antiquity of human race in India. Coal recently discovered in the country of Luni Pathans, south-east corner of Afghanistan. Progress of geological investigation in Godavari district, Madras Presidency. Subsidiary materials for artificial fuel.

Vol. VIII, 1875.

Part 1.—Annual report for 1874. The Altum-Artush considered from geological point of view. Evidences of 'ground-ice' in tropical India, during Talchir period. Trials of Raniganj fire-bricks.

Part 2 (out of print).—Gold-fields of south-east Wynaad, Madras Presidency. Geological notes on Khareean hills in Upper Punjab. Water-bearing strata of Surat district. Geology of Scindia's territories.

Part 3 (out of print).—Shahpur coal-field, with notice of coal explorations in Narbada region. Coal recently found near Moflong, Khasia Hills.

Part 4 (out of print).—Geology of Nepal. Raigarh and Hingir coal-fields.

Vol. IX, 1876.

Part 1 (out of print).—Annual report for 1875. Geology of Sind.

Part 2.—Retirement of Dr. Oldham. Age of some fossil floras in India. Cranium of Stegodon Ganesa, with notes on sub-genus and allied forms. Sub-Himalayan series in Jamu (Jammoo) Hills.

Part 3.—Fossil floras in India. Geological age of certain groups comprised in Gondwana series of India, and on evidence they afford of distinct zoological and botanical terrestrial regions in ancient epochs. Relations of fossiliferous strata at Maleri and Kota, near Sironcha, C. P. Fossil mammalian faunæ of India and Burma.

Part 4.—Fossil floras in India. Osteology of Merycopotamus dissimilis. Addenda and Corrigenda to paper on tertiary mammalia. Plesiosaurus in India. Geology of Pir Panjal and neighbouring districts.

Part 1.—Annual report for 1876. Geological notes on Great Indian Desert between Sind and Rajputana. Cretaceous genus Omphalia near Nameho lake, Tibet, about 75 miles north of Lhassa. Estheria in Gondwana formation. Vertebrata from Indian tertiary and secondary rocks. New Emydine from the upper tertiaries of Northern Punjab. Observations on under-ground temperature.

Part 2.—Rocks of the Lower Godavari. 'Atgarh Sandstones' near Cuttack. Fossil floras in India. New or rare mammals from the Siwaliks. Arvali series in North-eastern Rajputana. Borings for coal in India. Geology of India.

Part 3.—Tertiary zone and underlying rocks in North-west Punjab. Fossil floras in India. Erratics in Potwar. Coal explorations in Darjiling district. Limestones in neighbourhood of Barakar. Forms of blowing-machine used by smiths of Upper Assam. Analyses of Raniganj coals.

Part 4.—Geology of Mahanadi basin and its vicinity. Diamonds, gold, and lead ores of Sambalpur district. 'Eryon Comp. Barrovensis,' McCoy, from Sripermatur group near Madras. Fossil floras in India. The Blaini group and 'Central Gneiss' in Simla Himalayas. Tertiaries of North-West Punjab. Genera Chœromeryx and Rhagatherium.

VOL. XI, 1878.

Part 1.—Annual report for 1877. Geology of Upper Godavari basin, between river Wardha and Godavari, near Sironcha. Geology of Kashmir, Kishtwar, and Pangi. Siwalik mammals. Palæontological relations of Gondwana system. 'Erratics in Punjab.'

Part 2.—Geology of Sind (second notice). Origin of Kumaun lakes. Trip over Milam Pass, Kumaun. Mud volcanoes of Ramri and Cheduba. Mineral resources of Ramri, Cheduba and adjacent islands.

Part 3.—Gold industry in Wynaad. Upper Gondwana series in Trichinopoly and Nellore-Kistna districts. Senarmontite from Sarawak.

Part 4.—Geographical distribution of fossil organisms in India. Submerged forest on Bombay Island.

VOL. XII, 1879.

Part 1.—Annual report for 1878. Geology of Kashmir (third notice). Siwalik mammalia. Siwalik birds. Tour through Hangrang and Spiti. Mud eruption in Ramri Island (Arakan). Braunite, with Rhodonite, from Nagpur, Central Provinces. Palæontological notes from Satpura coal-basin. Coal importations into India.

Part 2.—Mohpani coal-field. Pyrolusite with Psilomelane at Gosalpur, Jabalpur district. Geological reconnaissance from Indus at Kushalgarh to Kurram at Thal on Afghan frontier. Geology of Upper Punjab.

Part 3.—Geological features of northern Madura, Pudukota State, and southern parts of Tanjore and Trichinopoly districts included within limits of sheet 80 of Indian Atlas. Cretaceous fossils from Trichinopoly district, collected in 1877-78. Sphenophyllum and other Equisetaceæ with reference to Indian form Trizygia Speciosa, Royle (Sphenophyllum Trizygia, Ung.). Mysorin and Atacamite from Nellore district. Corundum from Khasi Hills. Joga neighbourhood and old mines on Nerbudda.

Part 4.—'Attock Slates' and their probable geological position. Marginal bone of undescribed tortoise, from Upper Siwaliks, near Nila, in Potwar, Punjab. Geology of North Arcot district. Road section from Murree to Abbottabad.

VOL. XIII, 1880.

Part 1.—Annual report for 1879. Geology of Upper Godavari basin in neighbourhood of Sironcha. Geology of Ladak and neighbouring districts. Teeth of fossil fishes from Ramri Island and Punjab. Fossil genera Nōggerathia, Stbg., Nōggerathiopsis, Fstm., and Rhiptozamites, Schmalh., in palæozoic and secondary rocks of Europe, Asia, and Australia. Fossil plants from Kattywar, Shekh Budin, and Sirgujah. Volanic foci of eruption in Konkan.

Part 2.—Geological notes. Palæontological notes on lower trias of Himalayas. Artesian wells at Pondicherry, and possibility of finding sources of water-supply at Madras.

Part 3.—Kumaun lakes. Celt of palæolithic type in Punjab. Palæontological notes from Karharbari and South Rewa coal-fields. Correlation of Gondwana flora with other floras. Artesian wells at Pondicherry. Salt in Rajputana. Gas and mud eruptions on Arakan coast on 12th March 1879 and in June 1843.

Part 4.—Pleistocene deposits of Northern Punjab, and evidence they afford of extreme climate during portion of that period. Useful minerals of Arvali region. Correlation of Gondwana flora with that of Australian coal-bearing system. Reh or alkali soils and saline well waters. Reh soils of Upper India. Naini Tal landslip, 18th September 1880.

Vol. XIV, 1881.

Part 1.—Annual report for 1880. Geology of part of Dardistan, Baltistan, and neighbouring districts. Siwalik carnivora. Siwalik group of Sub-Himalayan region. South Rewah Gondwana basin. Ferruginous beds associated with basaltic rocks of north-eastern Ulster, in relation to Indian laterite. Rajmahal plants. Travelled blocks of the Punjab. Appendix to 'Palæontological notes on lower trias of Himalayas.' Mammalian fossils from Perim Island.

Part 2.—Nahan-Siwalik unconformity in North-Western Himalaya. Gondwana vertebrates. Ossiferous beds of Hundes in Tibet. Mining records and mining record office of Great Britain; and Coal and Metalliferous Mines Act of 1872 (England). Cobaltite and danaite from Khetri mines, Rajputana; with remarks on Jaipurite (Syepoorite). Zinc-ore (Smithsonite and Blende) with barytes in Karnul district, Madras. Mud eruption in island of Cheduba.

Part 3.—Artesian borings in India. Oligoclase granite at Wangtu on Sutlej, North-West Himalayas. Fish-palate from Siwaliks. Palæontological notes from Hazaribagh and Lohardagga districts. Fossil carnivora from Siwalik hills.

Part 4.—Unification of geological nomenclature and cartography. Geology of Arvali region, central and eastern. Native antimony obtained at Pulo Obin, near Singapore. Turgite from Juggiapett, Kistnah district, and zinc carbonate from Karnul, Madras. Section from Dalhousie to Pangi, *viâ* Sach Pass. South Rewah Gondwana basin. Submerged forest on Bombay Island.

Vol. XV, 1882.

Part 1.—Annual report for 1881. Geology of North-West Kashmir and Khagan. Gondwana labyrinthodonts. Siwalik and Jamna mammals. Geology of Dalhousie, North-West Himalaya. Palm leaves from (tertiary) Murree and Kasauli beds in India. Iridosmine from Noa-Dihing river, Upper Assam, and Platinum from Chutia Nagpur. On (1) copper mine near Yongri hill, Darjiling district; (2) arsenical pyrites in same neighbourhood; (3) kaolin at Darjiling. Analyses of coal and fire-clay from Makum coal-field, Upper Assam. Experiments on coal of Pind Dadun Khan, Salt-range, with reference to production of gas, made April 29th, 1881. Proceedings of International Congress of Bologna.

Part 2.—Geology of Travancore State. Warkilli beds and reported associated deposits at Quilon, in Travancore. Siwalik and Narbada fossils. Coal-bearing rocks of Upper Rer and Mand rivers in Western Chutia Nagpur. Pench river coal-field in Chhindwara district, Central Provinces. Borings for coal at Engsein, British Burma. Sapphires in North-Western Himalaya. Eruption of mud volcanoes in Cheduba.

Part 3.—Coal of Mach (Much) in Bolan Pass, and of Sharigh on Harnai route between Sibi and Quetta. Crystals of stilbite from Western Ghats, Bombay. Traps of Darang and Mandi in North-Western Himalayas. Connexion between Hazara and Kashmir series. Umaria coal-field (South Rewah Gondwana basin). Daranggiri coal-field, Garo Hills, Assam. Coal in Myanoung division, Henzada district.

Part 4 (out of print).—Gold-fields of Mysore. Borings for coal at Beddadanol, Godavari district, in 1874. Supposed occurrence of coal on Kistna.

Vol. XVI, 1883.

Part 1.—Annual report for 1882. Richthofenia, Kays (Anomia Lawrenciana, Koninck) Geology of South Travancore. Geology of Chamba. Basalts of Bombay.

Part 2.—Synopsis of fossil vertebrata of India. Bijori Labyrinthodont. Skuli of Hippotherium antilopinum. Iron ores, and subsidiary materials for manufacture of iron, in north-eastern part of Jabalpur district. Laterite and other manganese-ore occurring at Gosulpore, Jabalpur district. Umaria coal-field.

Part 3.—Microscopic structure of some Dalhousie rocks. Lavas of Aden. Probable occurrence of Siwalik strata in China and Japan. Mastodon angustidens in India. Traverse between Almora and Mussooree. Cretaceous coal-measures at Borsora, in Khasia Hills, near Laour, in Sylhet.

Part 4.—Palæontological notes from Daltonganj and Hutar coal-fields in Chota Nagpur. Altered basalts of Dalhousie region in North-Western Himalayas. Microscopic structure of some Sub-Himalayan rocks of tertiary age. Geology of Jaunsar and Lower Himalayas. Traverse through Eastern Khasia, Jaintia, and North Cachar Hills. Native lead from Maulmain and chromite from the Andaman Islands. Fiery eruption from one of mud volcanoes of Cheduba Island, Arakan. Irrigation from wells in North-Western Provinces and Oudh.

Vol. XVII, 1884.

Part 1.—Annual report for 1883. Smooth-water anchorages or mud-banks of Narrakal and Alleppy on Travancore coast. Billa Surgam and other caves in Kurnool district. Geology of Chuari and Sihunta parganas of Chamba. Lyttonia, Waagen, in Kuling series of Kashmir.

Part 2.—Earthquake of 31st December 1881 Microscopic structure of some Himalayan granites and gneissose granites. Choi coal exploration. Re-discovery of fossils in Siwalik beds. Mineral resources of the Andaman Islands in neighbourhood of Port Blair. Intertrappean beds in Deccan and Laramie group in Western North America.

Part 3 (out of print).—Microscopic structure of some Arvali rocks. Section along Indus from Peshawar Valley to Salt-range. Sites for boring in Raigarh-Hingir coal-field (first notice). Lignite near Raipore, Central Provinces. Turquoise mines of Nishâpûr, Khorassan. Fiery eruption from Minbyin mud volcano of Cheduba Island, Arakan. Langrin coal-field, South-Western Khasia Hills. Umaria coal-field.

Part 4.—Geology of part of Gangasulan pargana of British Garhwal. Slates and schists imbedded in gneissose granite of North-West Himalayas. Geology of Takht-i-Suleiman. Smooth-water anchorages of Travancore coast. Auriferous sands of the Subansiri river. Pondicherry lignite, and phosphatic rocks at Musuri. Billa Surgam caves.

Vol. XVIII, 1885.

Part 1.—Annual report for 1884. Country between Singareni coal-field and Kistna river. Geological sketch of country between Singareni coal-field and Hyderabad. Coal and limestone in Doigrung river near Golaghat, Assam. Homotaxis, as illustrated from Indian formations. Afghan field notes.

Part 2.—Fossiliferous series in Lower Himalaya, Garhwal. Age of Mandhali series in Lower Himalaya. Siwalik camel (Camelus Antiquus, nobis ex Falc. and Caut. MS.). Geology of Chamba. Probability of obtaining water by means of artesian wells in plains of Upper India. Artesian sources in plains of Upper India. Geology of Aka Hills. Alleged tendency of Arakan mud volcanoes to burst into eruption most frequently during rains. Analyses of phosphatic nodules and rock from Mussooree.

Part 3.—Geology of Andaman Islands. Third species of Merycopotamus. Percolation as affected by current. Pirthalla and Chandpur meteorites. Oil-wells and coal in Thayetmyo district, British Burma. Antimony deposits in Maulman district. Kashmir earthquake of 30th May 1885. Bengal earthquake of 14th July 1885.

Part 4.—Geological work in Chhattisgarh division of Central Provinces. Bengal earthquake of 14th July 1885. Kashmir earthquake of 30th May 1885. Excavations in Billa Surgam caves. Nepaulite. Sabetmahet meteorite.

Vol. XIX, 1886.

Part 1.—Annual report for 1885. International Geological Congress of Berlin. Palæozoic Fossils in Olive group of Salt-range. Correlation of Indian and Australian coal-bearing beds. Afghan and Persian Field-notes. Section from Simla to Wangtu, and petrological character of Amphibolites and Quartz Diorites of Sutlej valley.

Part 2.—Geology of parts of Bellary and Anantapur districts. Geology of Upper Dehing basin in Singpho Hills. Microscopic characters of eruptive rocks from Central Himalayas. Mammalia of Karnul Caves. Prospects of finding coal in Western Rajputana. Olive group of Salt-range. Boulder-beds of Salt-range. Gondwana Homotaxis.

Part 3.—Geological sketch of Vizagapatam district, Madras. Geology of Northern Jesalmer. Microscopic structure of Malaini rocks of Arvali region. Malanjkhandi copper-ore in Balaghat district, C. P.

Part 4.—Petroleum in India. Petroleum exploration at Khâtan. Boring in Chhattisgarh coal-fields. Field-notes from Afghanistan: No. 3, Turkistan. Fiery eruption from one of mud volcanoes of Cheduba Island, Arakan. Nammianthal aerolite. Analysis of gold dust from Meza valley, Upper Burma.

Vol. XX, 1887.

Part 1.—Annual report for 1886. Field-notes from Afghanistan: No. 4, from Turkistan to India. Physical geology of West British Garhwal; with notes on a route traversed through Jaunsar-Bawar and Tiri-Garhwal. Geology of Garo Hills. Indian image-stones. Soundings recently taken off Barren Island and Narcondam. Talchir boulder-beds. Analysis of Phosphatic Nodules from Salt-range, Punjab.

Part 2.—Fossil vertebrata of India. Echinoidea of cretaceous series of Lower Narbada Valley. Field-notes: No. 5—to accompany geological sketch map of Afghanistan and North-Eastern Khorassan. Microscopic structure of Rajmahal and Deccan traps. Dolerite of Chor. Identity of Olive series in east with speckled sandstone in west of Salt-range in Punjab.

Part 3.—Retirement of Mr. Medlicott. J. B. Mushketoff's Geology of Russian Turkistan. Crystalline and metamorphic rocks of Lower Himalaya, Garhwal, and Kumaun, Section I. Geology of Simla and Jutogh. 'Lalitpur' meteorite.

Part 4.—Points in Himalayan geology. Crystalline and metamorphic rocks of Lower Himalaya, Garhwal, and Kumaun, Section II. Iron industry of western portion of Raipur. Notes on Upper Burma. Boring exploration in Chhattisgarh coal-fields. (Second notice). Pressure Metamorphism, with reference to foliation of Himalayan Gneissose Granite. Papers on Himalayan Geology and Microscopic Petrology.

Vol. XXI, 1888.

Part 1.—Annual report for 1887. Crystalline and metamorphic rocks of Lower Himalaya, Garhwal, and Kumaun, Section III. Birds'-nest of Elephant Island, Mergui Archipelago. Exploration of Jessalmer, with a view to discovery of coal. Facetted pebble from boulder bed ('speckled sandstone') of Mount Chel in Salt-range, Punjab. Nodular stones obtained off Colombo.

Part 2.—Award of Wollaston Gold Medal, Geological Society of London, 1888. Dharwar System in South India. Igneous rocks of Raipur and Balaghat, Central Provinces. Sangar Marg and Mehowgale coal-fields, Kashmir.

Part 3.—Manganese Iron and Manganese Ores of Jabalpur. 'The Carboniferous Glacial Period.' Pre-tertiary sedimentary formations of Simla region of Lower Himalayas.

Part 4.—Indian fossil vertebrates. Geology of North-West Himalayas. Blown-sand rock sculpture. Nummulites in Zanskar. Mica traps from Barakar and Raniganj.

Vol. XXII, 1889.

Part 1.—Annual report for 1888. Dharwar System in South India. Wajra Karur diamonds, and M. Chaper's alleged discovery of diamonds in pegmatite. Generic position of so-called Plesiosaurus Indicus. Flexible sandstone or Itacolumite, its nature, mode of occurrence in India, and cause of its flexibility. Siwalik and Narbada Chelonia.

Part 2.—Indian Steatite. Distorted pebbles in Siwalik conglomerate. 'Carboniferous Glacial Period.' Oil-fields of Twingoung and Beme, Burma. Gypsum of Nehal Nadi, Kumaun. Materials for pottery in neighbourhood of Jabalpur and Umaria.

Part 3.—Coal outcrops in Sharigh Valley, Baluchistan. Trilobites in Neobolus beds of Salt-range. Geological notes. Cherra Poonjee coal-field, in Khasia Hills. Cobaltiferous Matt from Nepál. President of Geological Society of London on International Geological Congress of 1888. Tin-mining in Mergui district.

Part 4.—Land-tortoises of Siwaliks. Pelvis of a ruminant from Siwaliks. Assays from Sambhar Salt-Lake in Rajputana. Manganiferous iron and Manganese Ores of Jabalpur. Palagonite-bearing traps of Rájmahál hills and Deccan. Tin-smelting in Malay Peninsula. Provisional Index of Local Distribution of Important Minerals, Miscellaneous Minerals, Gem Stones and Quarry Stones in Indian Empire. Part 1.

Vol. XXIII, 1890.

Part 1.—Annual report for 1889. Lakadong coal-fields, Jaintia Hills. Pectoral and pelvic girdles and skull of Indian Dicynodonts. Vertebrate remains from Nagpur district (with description of fish-skull). Crystalline and metamorphic rocks of Lower Himalayas, Garhwál and Kumaun, Section IV. Vivalves of Olive-group, Salt-range. Mud-banks of Travancore coasts.

Part 2.—Petroleum explorations in Harnai district, Baluchistan. Sapphire Mines of Kashmir. Supposed Matrix of Diamond at Wajra Karur, Madras. Sonapet Gold-field. Field notes from Shan Hills (Upper Burma). New species of Syringosphæridæ.

Part 3.—Geology and Economic Resources of Country adjoining Sind-Pishin Railway between Sharigh and Spintangi, and of country between it and Khattan. Journey through India in 1888-89, by Dr. Johannes Walther. Coal-fields of Lairungao, Maosandram, and Mao-belar-kar, in the Khasi Hills. Indian Steatite. Provisional Index of Local Distribution of Important Minerals, Miscellaneous Minerals, Gem Stones, and Quarry Stones in Indian Empire.

Part 4.—Geological sketch of Naini Tal; with remarks on natural conditions governing mountain slopes. Fossil Indian Bird Bones. Darjiling Coal between Lisu and Ramthi rivers. Basic Eruptive Rocks of Kadapah Area. Deep Boring at Lucknow. Coal Seam of Dore Ravine, Hazara.

VOL. XXIV, 1891.

Part 1.—Annual report for 1890. Geology of Salt-range of Punjab, with re-considered theory of Origin and Age of Salt-Mart. Graphite in decomposed Gneiss (Laterite) in Ceylon. Glaciers of Kabru, Pandim, etc. Salts of Sambhar Lake in Rajputana, and 'Reh' from Aligarh in North-Western Provinces. Analysis of Dolomite from Salt-range, Punjab.

Part 2.—Oil near Moghal Kot, in Sheráni country, Suleiman Hills. Mineral Oil from Suleiman Hills. Geology of Lushai Hills. Coal-fields in Northern Shan States. Reported Namsèka Ruby-mine in Mainglôn State. Tourmaline (Schorl) Mines in Mainglôn State. Salt-spring near Bawgyo, Thibaw State.

Part 3.—Boring in Daltongunj Coal-field, Palamow. Death of Dr. P. Martin Duncan. Pyroxenic varieties of Gneiss and Scapolite-bearing Rocks.

Part 4.—Mammalian Bones from Mongolia. Darjiling Coal Exploration. Geology and Mineral Resources of Sikkim. Rocks from the Salt-range, Punjab.

VOL. XXV, 1892.

Part 1.—Annual report for 1891. Geology of Thal Chotiáli and part of Mari country. Petrological Notes on Boulder-bed of Salt-range, Punjab. Sub-recent and Recent Deposits of valley plains of Quetta, Pishin, and Dasht-i-Bedaolat; with appendices on Chamans of Quetta; and Artesian water-supply of Quetta and Pishin.

Part 2 (out of print).—Geology of Saféd Kóh. Jherria Coal-field.

Part 3.—Locality of Indian Tscheffkinite. Geological Sketch of country north of Bhamo. Economic resources of Amber and Jade mines area in Upper Burma. Iron-ores and Iron Industries of Salem District. Riebeckite in India. Coal on Great Tenasserim River, Lower Burma.

Part 4.—Oil Springs at Moghal Kot in Shirani Hills. Mineral Oil from Suleiman Hills. New Amber-like Resin in Burma. Triassic Deposits of Salt-range.

VOL. XXVI, 1893.

Part 1.—Annual report for 1892. Central Himalayas. Jadeite in Upper Burma. Burmite, new Fossil Resin from Upper Burma. Prospecting Operations, Mergui District, 1891-92.

Part 2.—Earthquake in Baluchistan on 20th December 1892. Burmite, new amber-like fossil resin from Upper Burma. Alluvial deposits and Subterranean water-supply of Rangoon.

Part 3.—Geology of Sherani Hills. Carboniferous Fossils from Tenasserim. Boring at Chandernagore. Granite in Tavoy and Mergui.

Part 4.—Geology of country between Chappar Rift and Harnai in Baluchistán. Geology of part of Tenasserim Valley with special reference to Tendau-Kamapying Coal-field. Magnetite containing Manganese and Alumina. Hislopite.

VOL. XXVII, 1894.

Part 1.—Annual report for 1893. Bhaganwala Coal-field, Salt-range, Punjab.

Part 2.—Petroleum from Burma. Singareni Coal-field, Hyderabad (Deccan). Gohna Landslip, Garhwal.

Part 3.—Cambrian Formation of Eastern Salt-range. Giridih (Karharbari) Coal-fields. Chipped (?) Flints in Upper Miocene of Burma. Velates Schmideliana, Chemn., and Provelates grandis, Sow. sp., in Tertiary Formation of India and Burma.

Part 4.—Geology of Wuntho in Upper Burma. Echinoids from Upper Cretaceous System of Baluchistán. Highly Phosphatic Mica Peridotites intrusive in Lower Gondwana Rocks of Bengal. Mica-Hypersthene-Hornblende-Peridotite in Bengal.

VOL. XXVIII, 1895.

Part 1.—Annual report for 1894. Cretaceous Formation of Pondicherry. Early allusion to Barren Island. Bibliography of Barren Island and Narcondam from 1884 to 1894.

Part 2.—Cretaceous Rocks of Southern India and geographical conditions during later cretaceous times. Experimental Boring for Petroleum at Sukkur from October 1893 to March 1895. Tertiary system in Burma.

Part 3.—Jadeite and other rocks, from Tammaw in Upper Burma. Geology of Tochi Valley. Lower Gondwanas in Argentina.

Part 4.—Igneous Rocks of Giridih (Kurhurbaree) Coal-field and their Contact Effects. Vindhyan system south of Sone and their relation to so-called Lower Vindhyans. Lower Vindhyan area of Sone Valley. Tertiary system in Burma.

VOL. XXIX, 1896.

Part 1.—Annual report for 1895. Acicular inclusions in Indian Garnets. Origin and Growth of Garnets and of their Micropegmatitic intergrowths in Pyroxenic rocks.

Part 2.—Ultra-basic rocks and derived minerals of Chalk (Magnesite) hills, and other localities near Salem, Madras. Corundum localities in Salem and Coimbatore districts, Madras. Corundum and Kyanite in Manbhum district, Bengal. Ancient Geography of "Gondwanaland." Notes.

Part 3.—Igneous Rocks from the Tochi Valley. Notes.

Part 4.—Steatite mines, Minbu district, Burma. Lower Vindhyan (Sub-Kaimur) area of Sone Valley, Rewah. Notes.

VOL. XXX, 1897.

Part 1.—Annual report for 1896. Norite and associated Basic Dykes and Lava-flows in Southern India. Genus Vertebraria. On Glossopteris and Vertebraria.

Part 2.—Cretaceous Deposits of Pondicherri. Notes.

Part 3.—Flow structure in igneous dyke. Olivine-norite dykes at Coonoor. Excavations for corundum near Palakod, Salem District. Occurrence of coal at Palana in Bikanir. Geological specimens collected by Afghan-Baluch Boundary Commission of 1896.

Part 4.—Nemalite from Afghanistan. Quartz-barytes rock in Salem District, Madras Presidency. Worn femur of Hippopotamus irravadicus, Caut. and Falc., from Lower Pliocene of Burma. Supposed coal at Jaintia, Baxa Duars. Percussion Figures on micas. Notes.

VOL. XXXI, 1904.

Part 1 (out of print).—Prefatory Notice. Copper-ore near Komai, Darjeeling district. Zewan beds in Vihi district, Kashmir. Coal deposits of Isa Khel, Mianwali district, Punjab. Um-Rileng coal-beds, Assam. Sapphirine-bearing rock from Vizagapatam district. Miscellaneous Notes. Assays.

Part 2 (out of print).—Lt.-Genl. C. A. McMahon. Cyclobus Haydeni Diener. Auriferous Occurrences of Chota Nagpur, Bengal. On the feasibility of introducing modern methods of Coke-making at East Indian Railway Collieries, with supplementary note by Director, Geological Survey of India. Miscellaneous Notes.

Part 3 (out of print).—Upper Palæozoic formations of Eurasia. Glaciation and History of Sind Valley. Halorites in Trias of Baluchistan. Geology and Mineral Resources of Mayurbhanj. Miscellaneous Notes.

Part 4 (out of print).—Geology of Upper Assam. Auriferous Occurrences of Assam. Curious occurrence of Scapolite from Madras Presidency. Miscellaneous Notes. Index.

VOL. XXXII, 1905.

Part 1 (out of print).—Review of Mineral Production of India during 1898—1903.

Part 2 (out of print).—General report. April 1903 to December 1904. Geology of Provinces of Tsang and Ü in Tibet. Bauxite in India. Miscellaneous Notes.

Part 3 (out of print).—Anthracolithic Fauna from Subansri Gorge, Assam. Elephas Antiquus (Namadicus) in Godavari Alluvium. Triassic Fauna of Tropites-Limestone of Byans. Amblygonite in Kashmir. Miscellaneous Notes.

Part 4.—Obituary notices of H. B. Medlicott and W. T. Blanford. Kangra Earthquake of 4th April 1905. Index to Volume XXXII.

VOL. XXXIII, 1906.

Part 1 (out of print).—Mineral Production of India during 1904. Pleistocene Movement in Indian Peninsula. Recent Changes in Course of Nam-tu River, Northern Shan States. Natural Bridge in Gokteik Gorge. Geology and Mineral Resources of Narnaul District (Patiala State). Miscellaneous Notes.

Part 2 (out of print).—General report for 1905. Lashio Coal-field, Northern Shan States. Nanma, Mansang and Man-se-le Coal-fields, Northern Shan States, Burma. Miscellaneous Notes.

Part 3.—Petrology and Manganese-Ore Deposits of Sausar Tahsil, Chhindwara district, Central Provinces. Geology of parts of valley of Kanhan River in Nagpur and Chhindwara districts, Central Provinces. Manganite from Sandur Hills. Miscellaneous Notes.

Part 4 (out of print).—Composition and Quality of Indian Coals. Classification of the Vindhyan System. Geology of State of Panna with reference to the Diamond bearing Deposits. Index to Volume XXXIII.

VOL. XXXIV, 1906.

Part 1.—Fossils from Halorites Limestone of Bambanag Cliff, Kumaon. Upper-Triassic Fauna from Pishin District, Baluchistan. Geology of portion of Bhutan. Coal Occurrences in Foot-hills of Bhutan. Dandli Coal-field : Coal outcrops in Kotli Tehsil of Jammu State. Miscellaneous Notes.

Part 2.—Mineral Production of India during 1905. Nummulites Douvillei, with remarks on Zonal Distribution of Indian Nummulites. Auriferous Tracts in Southern India. Abandonment of Collieries at Warora, Central Provinces. Miscellaneous Notes.

Part 3.—Explosion Craters in Lower Chindwin district, Burma. Lavas of Pavagad Hill. Gibbsite with Manganese-ore from Talevadi, Belgaum district, and Gibbsite from Bhekowli, Satara District. Classification of Tertiary System in Sind with reference to Zonal distribution of Eocene Echinoidea.

Part 4 (out of print).—Jaipur and Nazira Coal-fields, Upper Assam. Makum Coal-field between Tirap and Namdang Streams. Kabat Anticline, near Seiktein, Myingyan district, Upper Burma. Asymmetry of Yenangyat-Singu Anticline, Upper Burma. Northern part of Gwegyo Anticline, Myingyan District, Upper Burma. Breynia Multituberculata, from Nari of Baluchistan and Sind. Index to Volume XXXIV.

VOL. XXXV, 1907.

Part 1.—General report for 1906. Orthophragmina and Lepidocyclina in Nummulitic Series. Meteoric Shower of 22nd October 1903 at Dokáchi and neighbourhood, Dacca District.

Part 2.—Indian Aerolites. Brine-wells at Bawgyo, Northern Shan States. Gold-bearing Deposits of Loi Twang, Shan States. Physa Prinsepii in Maestrichtian strata of Baluchistan. Miscellaneous Notes.

Part 3.—Preliminary survey of certain Glaciers in North-West Himalaya. A.—Notes on certain Glaciers in North-West Kashmir.

Part 4.—Preliminary survey of certain Glaciers in North-West Himalaya. B.—Notes on certain Glaciers in Lahaul. C.—Notes on certain Glaciers in Kumaon. Index to Volume XXXV.

VOL. XXXVI, 1907-08.

Part 1.—Petrological Study of Rocks from hill tracts, Vizagapatam district, Madras Presidency. Nepheline Syenites from hill tracts, Vizagapatam district, Madras Presidency. Stratigraphical Position of Gangamopteris Beds of Kashmir. Volcanic outburst of Late Tertiary Age in South Hsenwi, N. Shan States. New suidæ from Bugti Hills, Baluchistan. Permo-Carboniferous Plants from Kashmir.

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Part 3.—Marine fossils in Yenangyaung oil-field, Upper Burma. Fresh-water shells of genus Batissa in Yenangyaung oil-field, Upper Burma. New Species of Dendrophyllia from Upper Miocene of Burma. Structure and age of Taungtha hills, Myingyan district, Upper Burma. Fossils from Sedimentary rocks of Oman (Arabia). Rubies in Kachin hills, Upper Burma. Cretaceous Orbitoides of India. Two Calcutta Earthquakes of 1906. Miscellaneous Notes.

Part 4.—Pseudo-Fucoids from Pab sandstones at Fort Munro, and from Vindhyan series. Jadeite in Kachin Hills, Upper Burma. Wetchok-Yedwet Pegu outcrop. Magwe district, Upper Burma. Group of manganates, comprising Hollandite, Psilomelane and Coronadite. Occurrence of Wolfram in Nagpur district, Central Provinces. Miscellaneous Notes. Index to Volume XXXVI.

VOL. XXXVII, 1908-09.

Part 1.—General report for 1907. Mineral Production of India during 1907. Striated boulders in the Blaini formation.

Part 2.—Tertiary and Post-Tertiary Freshwater Deposits of Baluchistan and Sind. Geology and Minerals of Rajpipla. Suitability of Rajmahal sands for glass-making. Vredenburgite, Sitaparite and Juddite. Laterites from the Central Provinces. Miscellaneous notes.

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